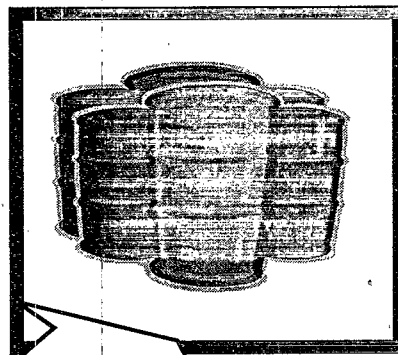
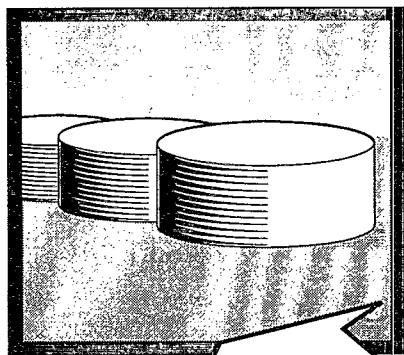
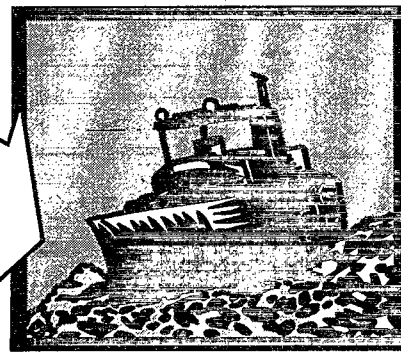
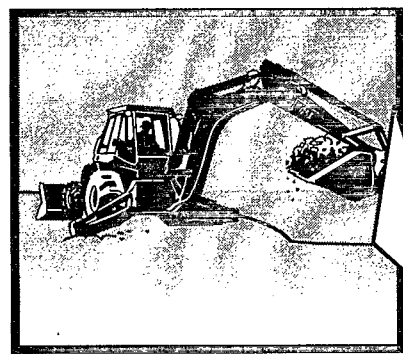


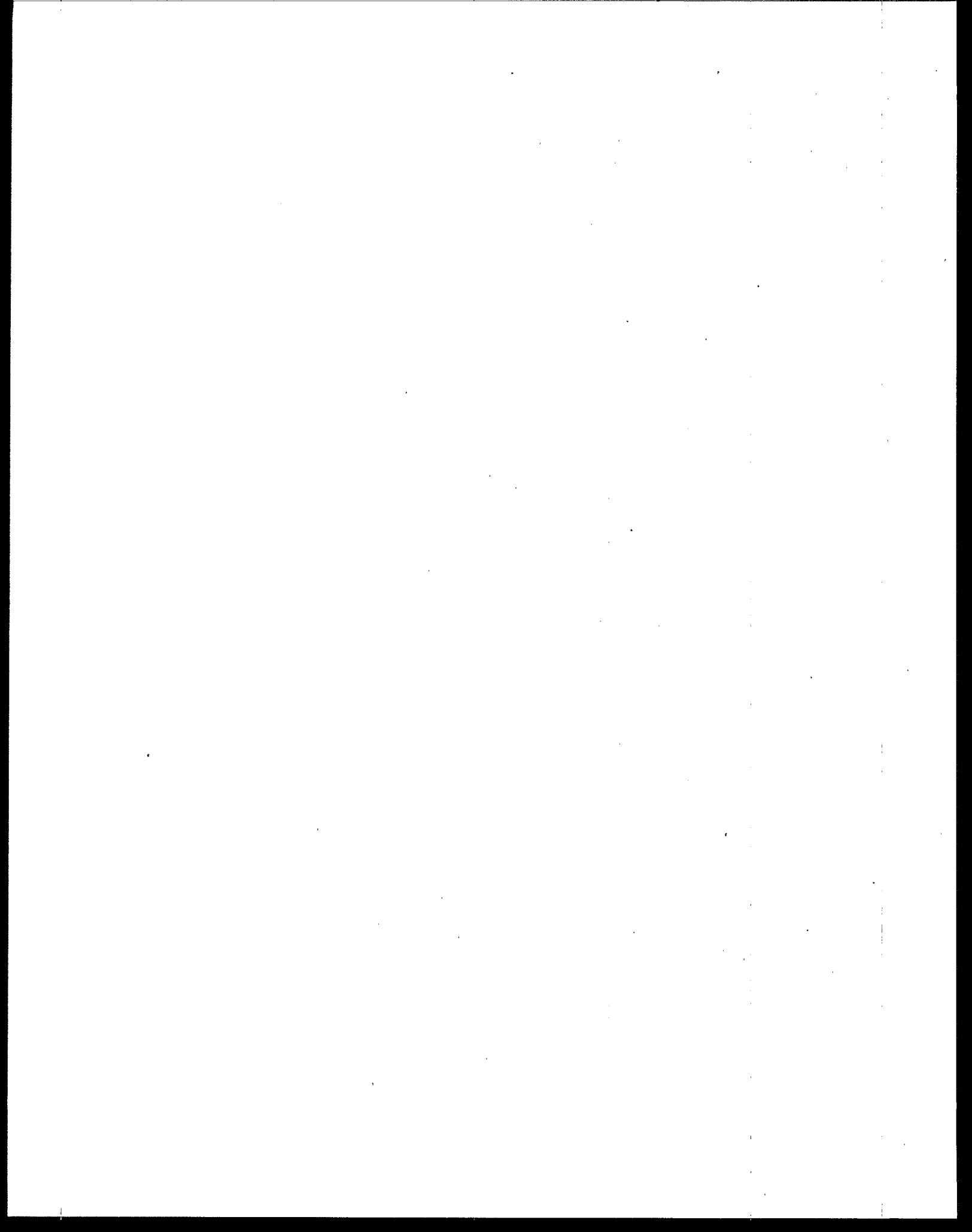


Potential Applicability of Assembled Chemical Weapons Assessment Technologies to RCRA Waste Streams and Contaminated Media



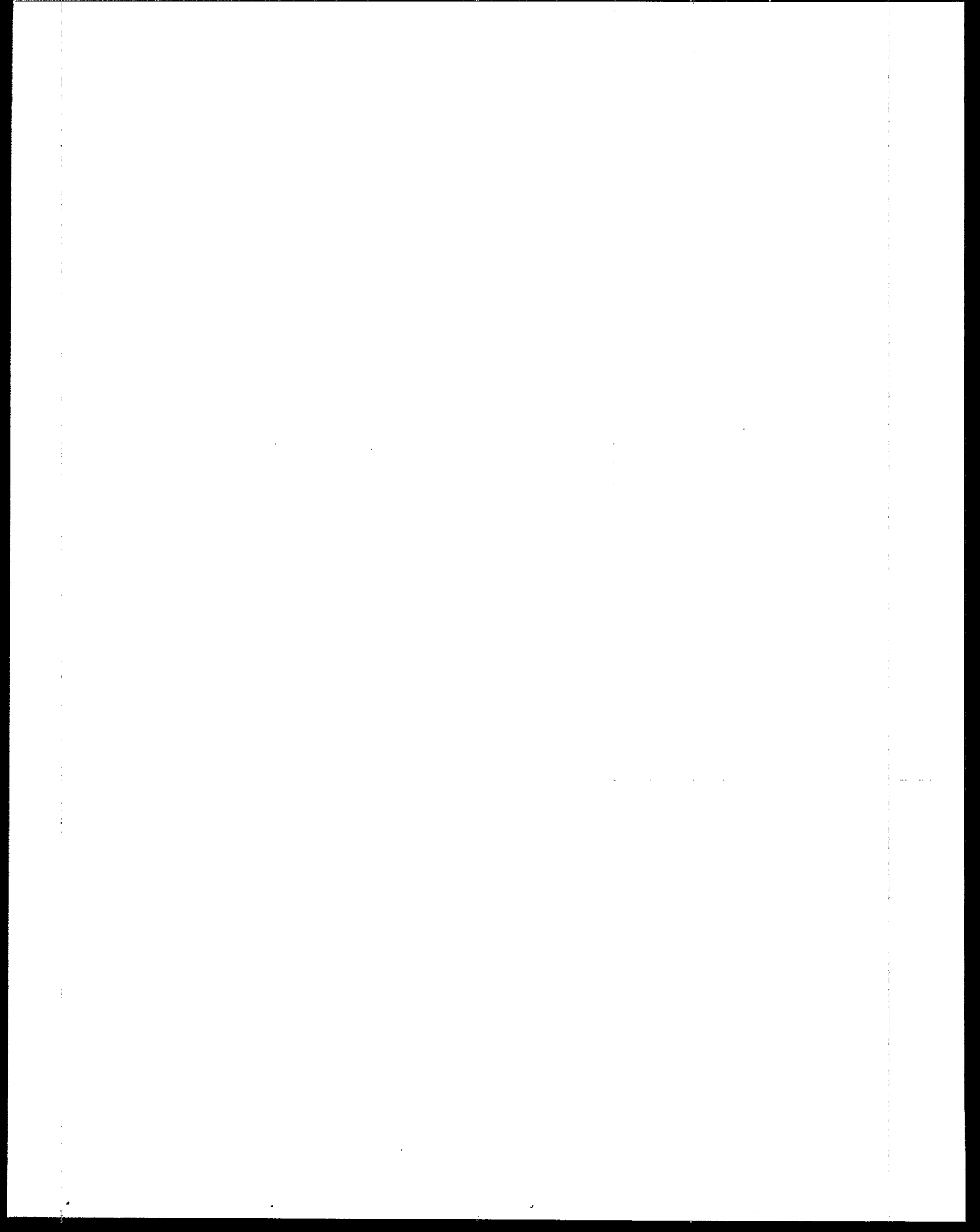
ACWA
Technologies





**POTENTIAL APPLICABILITY OF ASSEMBLED
CHEMICAL WEAPONS ASSESSMENT TECHNOLOGIES
TO RCRA WASTE STREAMS AND CONTAMINATED MEDIA**

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460



NOTICE AND DISCLAIMER

This document was prepared by the U.S. Environmental Protection Agency's Technology Innovation Office with support under EPA Contract Number 68-W-99-003. It is intended to raise the awareness of the technologies included in the Assembled Chemical Weapons Assessment (ACWA) program, and presents an overview of each technology, including its applicability, performance, and other factors. Information about the technologies was obtained from the technology providers. No testing or evaluation was conducted by EPA during preparation of this document, and an independent assessment of this information was beyond EPA's scope. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. For more information about this project, please contact: John Kingscott, U.S. Environmental Protection Agency, Technology Innovation Office, Ariel Rios Building, 1200 Pennsylvania Avenue, N.W. (MS 5102G), Washington, D.C., 20460; (703) 603-7189; e-mail: kingscott.john@epa.gov.

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ACKNOWLEDGMENTS

Special acknowledgment is given to the ACWA program staff and the technology providers for their thoughtful suggestions and support in preparing this report.

EXECUTIVE SUMMARY

This report provides an evaluation of the potential applicability of Assembled Chemical Weapons Assessment (ACWA) technologies to RCRA waste streams and contaminated media found at RCRA and Superfund sites. The information in this report is intended to provide site managers and other technology users with a better understanding of the potential uses of ACWA technologies and to help technology providers better understand the potential market for those and similar technologies. Under the ACWA program, the U.S. Department of Defense (DoD) has established a process for identifying and demonstrating alternatives to incineration for the demilitarization of chemical weapons. The seven ACWA technology providers and their technologies evaluated for this report are:

- AEA Technology PLC's SILVER II™ Technology
- AlliedSignal Inc.'s Immobilized Cell Bioreactor (ICB™) Technology (now known as Honeywell's ICB™ Technology)
- Commodore Advanced Sciences, Inc.'s Solvated Electron Technology (SET™)
- Eco Logic Inc.'s Gas Phase Chemical Reduction (GPCR) Technology
- Foster Wheeler Development Corporation's Supercritical Water Oxidation (SCWO) Technology
- General Atomic's Supercritical Water Oxidation (SCWO) Technology
- Startech Environmental Corporation's Plasma Waste Converter (PWC™) Technology

The U.S. Environmental Protection Agency (EPA) examined the status of these seven ACWA technologies and their potential to treat RCRA waste streams and contaminated media typically found at RCRA and Superfund sites, including those currently treated by incineration. EPA worked with DoD staff and the technology providers to collect available information about the types of RCRA waste streams and contaminated media that the ACWA technologies treated or could treat. Table ES-1 provides a summary of the ACWA technologies.

This report presents an overview of each technology, including its applicability, performance, and other factors to be considered. Information about the technologies was obtained from the technology providers and has not been verified independently by EPA. In addition, the report includes information about the potential for the application of and market for the ACWA technologies to treat RCRA wastes that have chemical structures similar to ACWA wastes.

Table ES-1. Summary of ACWA Technologies

Vendor and Technology	Technology Type (all ex situ)	Developmental Status	Contaminants Treated (Matrix)
AEA Technology PLC's SILVER II™	Electrochemical oxidation - uses reactive silver that is created by applying an electric current to a solution of nitric acid and silver nitrate	Pilot-scale	<ul style="list-style-type: none"> • Solvents (medical diagnostic wastes)
AlliedSignal (now Honeywell) Inc.'s Immobilized Cell Bioreactor™	Biological degradation - combines a high surface area media with a support matrix in a bioreactor	Field demonstration	<ul style="list-style-type: none"> • Chlorinated solvents (groundwater)
Commodore Advanced Sciences, Inc.'s Solvated Electron Technology™	Chemical reduction - uses solvated electron solutions that consist of alkali or alkaline earth metals such as sodium or calcium dissolved in liquid anhydrous ammonia	Full-scale; commercial treatment of PCB-contaminated wastes; has nationwide permit for treatment of PCBs	<ul style="list-style-type: none"> • CFCs (pure wastes) • DDD, DDE, DDT, Dieldrin (soil, wastes) • Dioxins/furans (oil) • Explosives (soil) • PAHs (pure) • PCBs (soil, oil, surfaces)
Eco Logic Inc.'s Gas Phase Chemical Reduction Technology	Chemical reduction - uses hydrogen gas at elevated temperatures	Full-scale; commercial treatment of PCB-contaminated wastes	<ul style="list-style-type: none"> • DDT (agricultural wastes) • Dioxins/furans (sediments) • Hexachlorobenzene (chemical industry wastes) • PAHs (sediments) • PCBs (soil, oil, sediments, groundwater, concrete, electrical equipment, process wastes)

Table ES-1. Summary of ACWA Technologies (continued)

Vendor and Technology	Technology Type (all ex situ)	Developmental Status	Contaminants Treated (Matrix)
Foster Wheeler Development Corporation's Supercritical Water Oxidation Technology	Hydrothermal oxidation - treats organic wastes at a combination of temperature and pressure higher than the critical point of water, where the wastes become highly soluble and functions as a fuel	Field demonstration	<ul style="list-style-type: none"> Chlorinated solvents (wastes typically found on naval vessels)
General Atomic's Supercritical Water Oxidation Technology	Hydrothermal oxidation - treats organic wastes at a combination of temperature and pressure higher than the critical point of water, where the wastes become highly soluble and functions as a fuel	Field demonstration	<ul style="list-style-type: none"> Chlorinated solvents (soil, groundwater, wastes typically found on naval vessels) Explosives (rocket propellants)
Startech Environmental Corporation's Plasma Waste Converter TM	Thermal plasma - uses plasma gas which is discharged within a chamber to produce very high temperatures	Pilot-scale	<ul style="list-style-type: none"> Chlorinated solvents (industrial wastes) Explosives (soil, waste streams) Heavy metals (soils, medical wastes)

Key results for the ACWA technologies; potential applicability to RCRA waste streams and contaminated media; cost; and potential market include the following.

ACWA Technologies

- The seven ACWA technologies are all operated *ex situ* and include chemical oxidation, chemical reduction, biological degradation, or thermal processes.** SILVER IITM is an electrochemical oxidation process; ICBTM is a biological degradation process; SETTM and GPCR are chemical reduction processes; the SCWO technologies are hydrothermal oxidation processes; and PWCTM is a thermal plasma process.
- Two ACWA technologies currently are being used for full-scale, commercial operations** (Commodore's SETTM facility in the U.S. and Eco Logic's GPCR facility in Kwinana, Australia) to treat PCB-contaminated wastes. **The others are under development** and have been tested on a number of different waste types at either bench or pilot and field-demonstration scales. Pilot- and demonstration-scale testing has been conducted for PCBs in soil (SETTM and GPCR); pesticides in soil (SETTM); chlorinated solvents in groundwater (ICBTM); PCBs in groundwater (GPCR); chlorinated solvents in wastes (SETTM, GPCR, and both SCWO technologies); explosives in wastes (SILVER

IITM and GPCR, and General Atomics' SCWO); and PCBs in wastes (SETTM and General Atomics' SCWO).

Potential Applicability to RCRA Waste Streams and Contaminated Media

- Six of the ACWA technologies (AEA's SILVER IITM; Commodore's SETTM; Eco Logic's GPCR; Foster Wheeler's SCWO; General Atomic's SCWO; and Startech's PWC) have the **capability to treat a wide range of organic compounds** (similar to incineration), while all seven technologies can treat other organic compounds with chemical structures similar to ACWA chemicals.
- While ACWA wastes are **typically treated in a liquid phase**, several of the ACWA technologies have the **capability to treat materials in solid, liquid, or gaseous phases**. SILVER IITM and PWCTM can treat solid and liquid materials directly, generally without preprocessing, while the use of other technologies may require some preprocessing. For the ICBTM, materials must be in an aqueous phase. For SETTM, materials must be susceptible to penetration by liquid ammonia; some solids must be crushed or shredded; and wet sludges may need to be dewatered before they are treated. For GPCR, materials must be volatilized or atomized before they are treated. Solids are generally passed through a thermal desorber prior to treatment in a GPCR. For SCWO, materials must be in a liquid phase or converted to a liquid phase. All seven ACWA technologies can treat aqueous wastes. ACWA technologies that can treat contaminated soil, sludge, or debris include SILVER IITM, SETTM, GPCR, and PWC. These vendors provide modular equipment that can be used for pre-or post-processing (before or after the primary system).
- The ACWA technologies have been **tested on various process wastes**, such as oil, organic liquids, and hydraulic fluids, ion exchange resins, nuclear industry wastes, and fuels; wastes from textile finishers, chemical manufacturers, wood treating facilities, and beverage and food processors; shredded or crushed concrete and metals; solid surfaces such as steel, wood, fiberglass, concrete, and rubber; electrical equipment; solid waste such as paper, cloth, and plastic; and contaminated media, such as soil, sediment, and groundwater.
- A number of RCRA waste streams include constituents that have chemical structures similar to ACWA wastes, including those that are ethers, esters, and nitrated compounds. While the technology providers did not provide data on the treatment of specific RCRA hazardous wastes, the analysis showed that all seven of the ACWA technologies have the **potential to treat RCRA wastes with chemical structures similar to those of the ACWA wastes**. In addition, as mentioned above, six of the ACWA technologies are capable of treating a wide range of organic compounds and therefore have the potential to treat a wide range of organic RCRA waste streams.

- The types of **constituents tested by various ACWA service providers** include chlorinated solvents, chlorofluorocarbons (CFCs), dioxins and furans, explosives, PCBs, and pesticides in such matrices as oil, soil, sediment, groundwater, and sludge. For example, SET™ has been demonstrated in pilot studies to treat organochlorine pesticides (DDD, DDE, DDT, and dieldrin) in soil to below detection limits.
- The **values for dioxins and furans measured in the ACWA program were all less than the emission standard for dioxins and furans from incinerators**, 0.20 ng/m³ TEQ (40 CFR 63.1203). All seven ACWA technologies generate off-gases, and the ACWA program provided limited results on the concentrations of dioxins or furans in the off-gases from the three treatment technologies included in 1999 demonstration testing. The ACWA program data showed the following concentrations of dioxins and furans in the off-gases, measured as toxicity equivalent quotient (TEQ, the international method of relating the toxicity of various dioxin and furan congeners to the toxicity of 2,3,7,8-TCDD): the AlliedSignal ICB™ was 0.064 ng/m³ TEQ; the General Atomics' SCWO ranged from 0.025-0.100 ng/m³ TEQ; and the Startech PWC™ was 0.100 ng/m³. In addition, all seven ACWA technology providers stated that the technologies are designed and operated so that they will not produce dioxins or dibenzofurans in the off-gases, therefore claiming potential as alternatives to incineration.

Cost

- Except for SET™, GPCR, and PWC™, the ACWA technologies are not available on a commercial scale. In addition, except for projected full-scale costs for SET™ and GPCR, **the technology providers did not provide quantitative cost information** for use of their technologies. EPA requested that all ACWA technology providers identify the cost for use of their technologies for treatment of RCRA wastes and contaminated media, and some provided limited information about cost, including projected full-scale costs. However, these costs were limited to select aspects of a given remediation (such as costs for electricity) and are not presented here because of concerns about comparability. The costs for remediation of contaminated sites using the ACWA technologies would vary based on site-specific factors such as matrix characteristics and the presence of debris.
- One of the criteria for accepting technologies into the ACWA program was that their **life cycle costs would be approximately comparable to those for incineration**. It is likely that additional information will be made available in the future about the costs for use of the ACWA technologies for treatment of RCRA wastes and contaminated media, after additional testing is completed for the ACWA technologies. Further, the ACWA technologies are at different scales of development, and it has been generally observed that it is difficult to accurately predict costs for use of a technology at a full scale until it is in common use.

Potential Market

- **The potential market for ACWA technologies includes wastes that currently are treated by combustion and organic wastes that are treated by other technologies or are disposed.** Approximately 3.3 million tons per year of wastes in the U.S. are managed by combustion, including wastes from the industrial organic chemicals, pesticides and agricultural chemicals, organic fibers, medicinal chemicals, and botanical products sectors. An evaluation of 16 RCRA wastes that have constituents with chemical structures similar to the ACWA wastes showed that the majority (by mass) of the RCRA wastes are managed by aqueous organic treatment or disposal (with or without treatment). For example, approximately 44 million tons per year of F003 spent solvent are managed by aqueous organic treatment and 23 million tons per year by disposal. Aqueous organic treatment used for RCRA wastes includes processes such as air/steam stripping, wet air oxidation, and chemical precipitation.
- **Other vendors provide processes that are similar to the ACWA technologies** (in terms of type of process, such as chemical oxidation and reduction, or thermal processes). Along with the ACWA technologies, they may provide additional options for treating organic wastes, including those treated by combustion. To identify such vendors, EPA searched its EPA REmediation And CHaracterization Innovative Technologies (EPA REACH IT) database, which includes information from 750 vendors of site remediation technologies. A search of EPA REACH IT identified seven vendors of similar technologies, including EnSolve Biosystems' Encell Bioreactor; Dames and Moore's Bioinfiltration; High Voltage Environmental Applications' E-Beam; Delphi Research's DETOXSM; G.E.M.'s chemical reaction process; En-Dyn's Low Temperature Plasma; and MSE Technology Applications' electron torch. However, the EPA REACH IT database likely does not include all vendors that may offer similar technologies (especially for treatment of wastes, rather than media), and some vendors that offer similar technologies were not identified in this evaluation.

CONTENTS

<u>Section</u>	<u>Page</u>
EXECUTIVE SUMMARY	ii
1.0 INTRODUCTION	1-1
2.0 DESCRIPTION OF ACWA TECHNOLOGIES	2-1
2.1 AEA's SILVER II™ Technology	2-4
2.1.1 Technology Description	2-4
2.1.2 Available Performance and Cost Data	2-6
2.1.3 Results from ACWA Demonstration Testing	2-7
2.2 AlliedSignal's Immobilized Cell Bioreactor™ (ICB™) Technology	2-7
2.2.1 Technology Description	2-7
2.2.2 Available Performance and Cost Data	2-7
2.2.3 Results from ACWA Demonstration Testing	2-10
2.3 Commodore's Solvated Electron Technology	2-11
2.3.1 Technology Description	2-11
2.3.2 Available Performance and Cost Data	2-13
2.3.3 Results from ACWA Testing	2-17
2.4 Eco Logic's Gas Phase Chemical Reduction Technology	2-17
2.4.1 Technology Description	2-17
2.4.2 Available Performance and Cost Data	2-18
2.4.3 Results from the ACWA Testing Program	2-23
2.5 Foster Wheeler's Supercritical Water Oxidation Technology	2-23
2.5.1 Technology Description	2-23
2.5.2 Available Performance and Cost Data	2-25
2.5.3 Results from ACWA Demonstration Testing	2-26
2.6 General Atomics' SCWO Technology	2-26
2.6.1 Technology Description	2-27
2.6.2 Available Performance and Cost Data	2-28
2.6.3 Results from ACWA Demonstration Testing	2-30
2.7 Startech's Plasma Waste Converter Technology	2-30
2.7.1 Technology Description	2-31
2.7.2 Available Performance and Cost Data	2-32
2.7.3 Results from ACWA Demonstration Testing	2-34

3.0	POTENTIAL FOR APPLICATION OF ACWA TECHNOLOGIES TO TREAT RCRA WASTE STREAMS COMPARABLE TO ACWA WASTES	3-1
3.1	Applicability to Treating RCRA Wastes Currently Treated by Combustion	3-1
3.2	Applicability to Treating RCRA Appendix VIII Wastes with Chemical Structures Similar to ACWA Chemicals	3-5
4.0	POTENTIAL FOR APPLICATION OF ACWA TECHNOLOGIES TO TREAT CONTAMINATED WASTES AND MEDIA	4-1
5.0	REFERENCES	5-1

APPENDIX A

A-1	Additional Background on the ACWA Program	A-1
A-2	Summary of ACWA Technology Service Providers and Technologies Relevant to EPA Effort .	A-3
A-3	Points of Contact at ACWA Technology Service Providers and their Team Members	A-4

APPENDIX B

B-1	Vendors Listed in EPA REACH IT as Providing Technologies Similar to ACWA Technologies	B-3
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APPENDIX C

C-1	Management Methods for Selected Liquid Wastes Generated and Managed On Site and Received from Off Site for Management	C-2
C-2	Management Methods for Selected Solid and Sludge Wastes Generated and Managed On Site and Received from Off Site for Management	C-3
C-3	Management Methods for Selected Liquid Wastes Generated and Managed On Site	C-4
C-4	Management Methods for Selected Liquid Wastes Received from Off Site for Management ...	C-5
C-5	Management Methods for Selected Solid and Sludge Wastes Generated and Managed On Site .	C-6
C-6	Management Methods for Selected Solid and Sludge Wastes Received from Off Site for Management	C-7
C-7	RCRA BRS System Type Codes and Descriptions	C-8

EXHIBITS

<u>Exhibit</u>	<u>Page</u>
2-1 Summary of Available Performance and Cost Information for the Seven ACWA Technologies	2-2
2.2-1 Concentrations in Groundwater Prior to Treatment	2-9
2.2-2 Summary of Constituent Concentrations in Southfield, Michigan Field Demonstration	2-10
2.3-1 Advantages and Potential Limitations of Commodore's SET™ Process	2-12
2.3-2 Summary of Performance Data on the SET™ Process by Contaminant and Matrix Type - Superfund and RCRA wastes	2-13
2.4-1 Summary of Full-Scale GPCR Operations	2-19
2.4-2 Summary of Pilot/Demonstration-Scale GPCR Operations	2-19
2.4-3 Summary of Laboratory-Scale Testing of GPCR	2-20
2.4-4 Summary of Average Operating Conditions During SITE Demonstration	2-21
2.4-5 Summary of Key Results from SITE Demonstration	2-21
2.4-6 Projected Costs for Three Scenarios Using GPCR Technology, Based on 1994 SITE Demonstration	2-22
2.5-1 Summary of DARPA/ONR Testing for Foster Wheeler SCWO	2-26
2.6-1 Summary of DARPA/ONR Testing for General Atomics' SCWO	2-29
2.7-1 Emissions of Plasma Converted Gas from Processed Hazardous Medical Waste	2-33
2.7-2 Composition of Silicate Stone from Processing of Lead Contaminated Soil	2-34
3-1 Summary of Industrial Sectors Generating Combusted RCRA Wastes	3-3
3-2 Unit Cost for Use of Incineration	3-5
3-3 Commercial Incinerator Prices	3-5
3-4 Comparison of Types of ACWA Wastes and RCRA Wastes	3-6
3-5 Management Methods for Selected Wastes Generated and Managed On Site	3-9
4-1 Summary of the Prior Work Completed by ACWA Technology Service Providers for Treatment of Contaminated Wastes and Media	4-2
4-2 Summary of Key Technical Factors for Use of the ACWA Technologies	4-3

FIGURES

<u>Figure</u>	<u>Page</u>
2.1.1: Process Flow Diagram for AEA's SILVER II™ Technology	2-5
2.2.1: Process Flow Diagram for AlliedSignal's ICB™ Technology	2-8
2.2.2: Bioremediation System Used in Field Demonstration	2-9
2.3.1: Process Flow Diagram for Commodore's SET™ Process for Liquid Wastes	2-12
2.4.1: Process Flow Diagram for Eco Logic's GPCR Technology	2-18
2.5.1: Process Flow Diagram of Foster Wheeler's SCWO	2-24
2.5.2: Transpiring Wall Reactor Used in Foster Wheeler's SCWO Technology	2-25
2.6.1: Process Flow Diagram for General Atomic's SCWO Technology	2-28
2.7.1: Startech's PWC™ Technology	2-31
2.7.2: Startech's PWC™ Process Flow Diagram	2-32
3-1: RCRA Waste Quantities Managed by Combustion Systems (EPA, 1999)	3-2
3-2: Hazardous Waste Codes Used in this Analysis	3-7

1.0 INTRODUCTION

Background

The National Defense Appropriations Act for Fiscal Year 1997 established the Assembled Chemical Weapons Assessment (ACWA) program within the U.S. Department of Defense (DoD) to identify and demonstrate alternatives to incineration for the demilitarization of chemical weapons. As part of the program, technology providers submitted proposals for demonstrating alternative technologies. Technology providers included companies or teams of companies including technology integrators and technology vendors. In addition, proposals included one or more technologies. Six technology providers, representing seven technologies used to treat chemical weapons, were selected for participation in the ACWA program. Three technologies were selected for demonstration testing in 1999 and four technologies for demonstration testing in 2000. The ACWA technology providers and technologies are (1) AEA Technology PLC (SILVER II™); (2) Parsons/AlliedSignal, now known as Honeywell (AlliedSignal's Immobilized Cell Bioreactor™); (3) Teledyne-Commodore LLC (Commodore's Solvated Electron Technology™); (4) Lockheed Martin - Eco Logic and Foster Wheeler (Eco Logic's Gas Phase Chemical Reduction and Foster Wheeler's Supercritical Water Oxidation); (5) General Atomics (Supercritical Water Oxidation); and (6) Burns and Roe (Startech's Plasma Waste Converter™). Additional information about the ACWA program is provided in Appendix A-1.

Because the ACWA technologies have the potential to treat non-chemical weapons wastes, the U. S. Environmental Protection Agency (EPA) has undertaken an effort to assess whether these technologies could be used to treat wastes and contaminated media typically found at RCRA and Superfund sites, including those currently treated by incineration. For example, much of the organic hazardous wastes at these sites are being treated by incineration to meet the RCRA Land Disposal Restrictions (LDR) treatment standards.

In 1999, EPA worked with the ACWA program staff and the technology providers to collect available and relevant information about the technologies and evaluated the potential applicability of ACWA technologies to RCRA waste streams and contaminated media. This report presents the results of EPA's evaluation of seven ACWA technologies. The report is intended to assist site managers and other technology users in understanding the potential uses of ACWA technologies and to help technology providers better understand the potential market for those technologies.

Information on technology performance and cost provided in this report was obtained from the ACWA technology providers, and EPA did not perform an independent evaluation of this information. Information in this report is not intended to revise or update EPA policy or guidance on how to treat RCRA hazardous waste or clean up sites with contaminated soil and groundwater. In addition, information presented in this report has no bearing on any of the activities being conducted by the DoD or the Dialogue on ACWA about the demilitarization of assembled chemical munitions.

Organization of This Report

Section 2 of this report provides a summary of the ACWA technologies, including a description of the process and a summary of the available performance and cost data. RCRA waste streams that are potentially comparable to ACWA wastes are described in Section 3, to provide an indication of the types of RCRA wastes that may potentially be treated by the ACWA technologies. Section 4 discusses the

potential for application of ACWA technologies to treat contaminated wastes and media, and includes a summary of the prior work.

Appendix A includes additional background information about the ACWA program, and contact information for the ACWA technology providers. Appendix B provides information about technology providers other than those in the ACWA program that offer technologies similar to those in the ACWA program (e.g., chemical oxidation and reduction technologies). These other providers may help technology users to generalize about the supply of these types of technologies. Appendix C provides a detailed summary of results from several queries of EPA's Biennial Reporting System for selected RCRA wastes.

2.0 DESCRIPTION OF ACWA TECHNOLOGIES

The seven ACWA technologies that were evaluated for this report are:

- AEA's SILVER II™ Technology
- AlliedSignal's Immobilized Cell Bioreactor Technology (now known as Honeywell's Immobilized Cell Bioreactor Technology)
- Commodore's Solvated Electron Technology
- Eco Logic's Gas Phase Chemical Reduction Technology
- Foster Wheeler's Supercritical Water Oxidation Technology
- General Atomic's Supercritical Water Oxidation Technology
- Startech's Plasma Waste Converter Technology

Exhibit 2-1 provides a summary of the available performance and cost data for these ACWA technologies. The remainder of this section provides a summary of these technologies, including a description of the process and a summary of the performance and cost data available for the technology, including the results from the recent testing conducted under the ACWA program. The information presented in this section is based on information obtained from the technology providers and has not been independently verified by EPA.

Exhibit 2-1. Summary of Available Performance and Cost Information for the Seven ACWA Technologies*

ACWA Technology Provider	Technology Used to Treat Chemical Weapons	Performance Data Provided	Cost Information Provided	Technology Included in 1999 ACWA Demonstration Testing (Demo I)
AEA	SILVER II™	Bench-scale testing of two solvent-containing mixtures	Amount of electricity required to destroy several organic compounds	No
AlliedSignal (now known as Honeywell)	Biotreatment	Field demonstration of a combined anaerobic-aerobic system for treatment of chlorinated solvent-contaminated groundwater	General information on cost-competitiveness	Yes
Commodore	Solvated Electron Technology (SET™)	Multiple applications - e.g., for U.S. Navy, New York State utility, Federal Superfund site	Projected full-scale costs, based on scale up studies of batch and continuous units to treat solid and liquid wastes	No
Eco Logic	Gas Phase Chemical Reduction (GPCR)	Multiple applications - e.g., for commercial operations in Australia and Canada, SITE demonstration	Projected full-scale costs from the SITE demonstration, and factors that affect project costs	No
Foster Wheeler	Supercritical Water Oxidation (SCWO)	Pilot-scale testing of hazardous wastes for the U.S. Navy	None	No
General Atomics	SCWO	Multiple pilot-scale demonstrations for U.S. Navy, Air Force, and Army	None **	Yes

**Exhibit 2-1. Summary of Available Performance and Cost Information for the
Seven ACWA Technologies* (continued)**

ACWA Technology Provider	Technology Used to Treat Chemical Weapons	Performance Data Provided	Cost Information Provided	Technology Included in 1999 ACWA Demonstration Testing (Demo I)
Startech	Plasma Waste Converter™	Pilot and full-scale testing of hazardous and non-hazardous wastes for commercial and government clients	None	Yes

* EPA requested from each technology provider information about the cost for use of their technology to treat RCRA waste streams and contaminated media. The technology providers made available to EPA only limited information about the cost for use of their technology. This information is being provided in this table and the remainder of Section 2 of this report because it provides a limited indication of the costs of the ACWA technologies. EPA recognizes that these data are not complete nor are they comparable between the technologies. For example, some vendors provided information such as amount of electricity required. EPA notes that it is not appropriate at this time to perform a comprehensive cost comparison among these technologies based on the information in this report. Further, as discussed later in this report, some of the ACWA technologies are still in the process of being commercialized, and cost data for use of these technologies at a full-scale are not yet available.

** Although cost data were not provided for this report, General Atomics indicated that projected full-scale costs are available for ACWA and Newport chemical agent demilitarization applications

2.1 AEA's SILVER II™ Technology

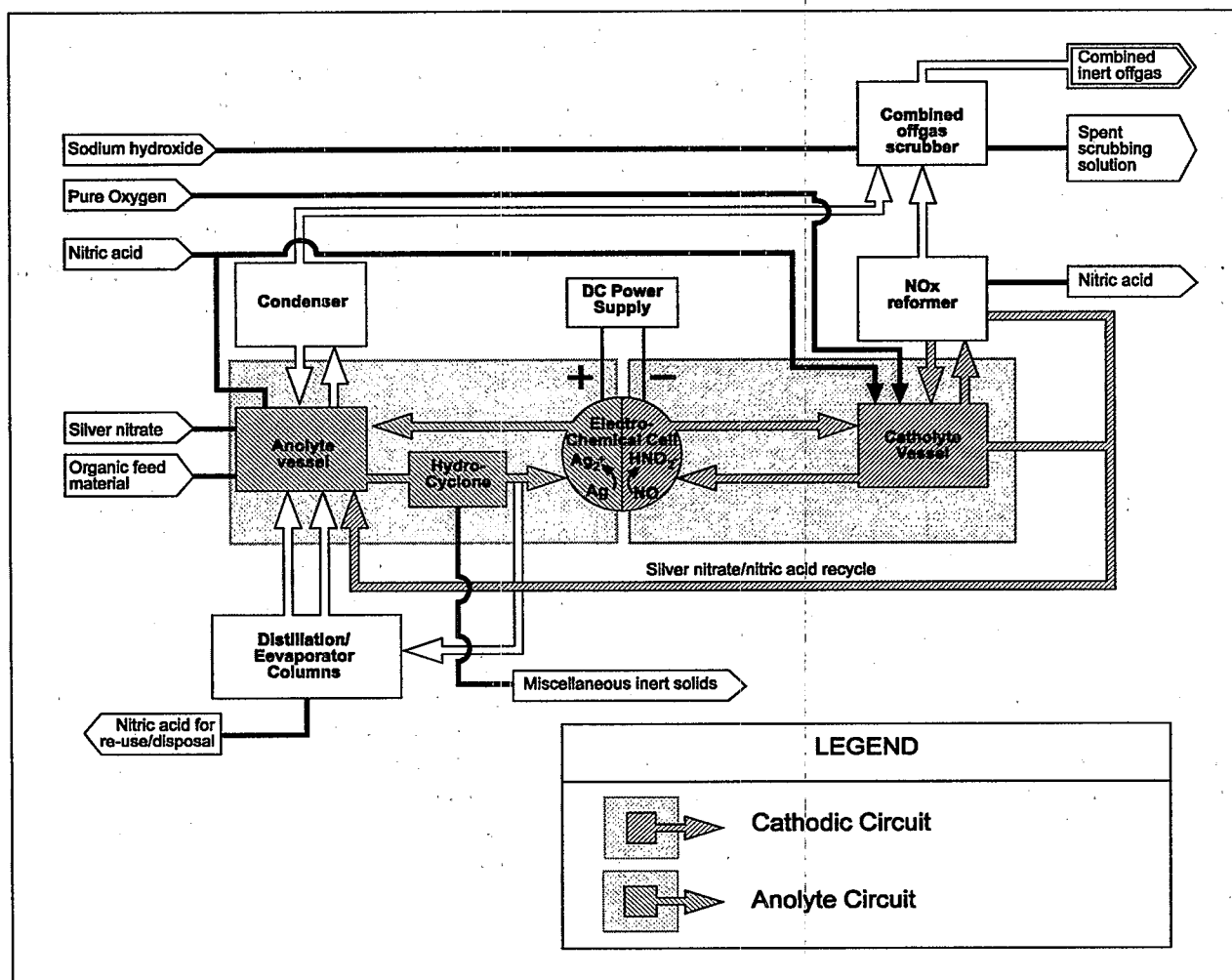
SILVER II™ is an electrochemical oxidation process, developed by AEA, based on the use of reactive silver. The SILVER II™ process was initially developed to destroy organic wastes generated by the nuclear industry in Great Britain. A 4 kW SILVER II™ demonstration plant, built in Dounreay, Scotland, in Great Britain, has been used to test the destruction of a variety of waste materials.

An additional 4kW SILVER II™ plant was built at the UK Ministry of Defense chemical weapons base at Porton Down, England. This plant was used to demonstrate the ability of the SILVER II process to destroy the chemical warfare agents VX and mustard. The result of these trials, which were conducted in 1996, was that 18 kg of mustard and 15 kg of VX were destroyed to an efficiency level of $\geq 99.9999\%$. (Boylston, October 1999)

2.1.1 Technology Description

Figure 2.1.1 is a process flow diagram of AEA's SILVER II™ technology. As shown on this figure, the technology consists of anolyte and catholyte vessels separated by an electrochemical cell. Organic material is fed into the anolyte vessel where it is oxidized in a solution of nitric acid to which silver nitrate has been added. When electric current is applied to the electrochemical cell, the silver is converted to silver++ ("Silver 2"), which is an extremely active oxidizing agent. This action oxidizes the organic feed to carbon dioxide, nitrogen oxides, water, mineral acids, and salts. Materials can be fed by gravity or by pumping, and can be solid (such as PCB-laced wooden pallets) or liquid. Off gases from the anolyte vessel are passed through a condenser, with condensed liquid returned to the anolyte vessel, and off gases passed through a scrubber and potentially through an activated carbon filter before being discharged to the atmosphere. The SILVER II™ process operates at relatively low temperature and pressure (up to 90°C and nominally atmospheric pressure). By-products of the process include salts (referred to on Figure 2.1.1 as miscellaneous inert solids), nitric acid, spent scrubbing solutions, and off gases. AEA reports that there are low volumes of by-product streams (gaseous, liquid, and solid), and that dioxins and dibenzofurans are not produced by the process.

Figure 2.1.1: Process Flow Diagram for AEA's SILVER II™ Technology (AEA, Not Dated)



2.1.2 Available Performance and Cost Data (Boylston, May 1999)

AEA reported that the SILVER II™ process has been used to destroy the following types of organic compounds: general industrial wastes, such as organic ion exchange resins, chlorinated hydrocarbons, hydrocarbons, mixed PCBs, and oils and hydraulic fluids; nuclear industry wastes; explosives; and fuels.

AEA provided available data on the use of SILVER II™ technology to treat hazardous constituents frequently identified at RCRA and Superfund sites, such as chlorinated solvents. This included information about bench-scale testing of two solvent-containing mixtures, conducted in 1992. The tested materials were radioactive solvent mixtures, labeled or contaminated with C_{14} and H_3 , and were wastes from the manufacture of medical diagnostic kits and other items. The purpose of the testing (referred to as "proof of principle") was to determine if such solvents could be oxidized by SILVER II™ and that the resulting radioactivity could be retained in the process. The solvent mixtures had the following compositions:

<u>Mix 1 (volume %)</u>		<u>Mix 2 (volume %)</u>	
Methanol	18.3	Water	47.5
Ethanol	18.3	Methanol	47.5
Isopropanol	18.3	40/60 petroleum spirits	1.7
Toluene	5	Chloroform	1.7
Chlorobenzene	5	Carbon Tetrachloride	1.7
Dioxan	3.3		
Tetrahydrofuran	3.3		
Diethylether	3.3		
Methylene Chloride	5		
Chloroform	5		
Cyclohexane	15		

The bench-scale tests were conducted on a batch basis using 28 ml portions of the solvent mixtures over a 12-hour period and were carried out at a 20°C anolyte temperature. The results from the bench-scale tests showed that recovery of both C_{14} and H_3 were approximately 98%. The results for the organic constituents showed that not all the wastes were destroyed during the 12-hour test, based on an analysis of total organic carbon in the anolyte. However, quantitative information about the specific organic compounds that remained in the anolyte, and their concentrations, was not provided. The performance results were attributed to the low bulk concentration and resulting slow oxidation kinetics. However, AEA reported that their 12 years of development work have shown that when organics react with SILVER II™, they are completely mineralized, and that no detectable quantities of organic feed material remain.

Limited data were provided by AEA about the cost for using the SILVER II™ technology. AEA indicated that a key factor affecting cost is electrochemical efficiency (affecting cost of electricity), and provided the following information about the amount of electricity required to destroy several organic compounds to carbon dioxide:

<u>Compound</u>	Amount of Electricity Required to Destroy Compound kW-hrs/kg (to CO₂)
Carbon tetrachloride	0 (strictly, CCl ₄ → CO ₂ is hydrolysis, not oxidation)
Dioxin	12.28
PCB (Aroclor 54)	9.85
Tetrachloroethene	1.61
1,1,1-Trichloroethane	4
Trichloroethene	3.06

2.1.3 Results from ACWA Demonstration Testing

SILVER II™ was one of the six technologies selected for evaluation under the ACWA program for the investigation of potential non-incineration destruction of chemical weapons and their components. Funding limitations resulted in three of the six technologies being demonstrated in FY99, with the remaining four (including SILVER II™) being demonstrated in FY00.

2.2 AlliedSignal's Immobilized Cell Bioreactor™ (ICB™) Technology

The AlliedSignal ICB™ is a biological technology for treatment of organic constituents in wastewater and groundwater. (AlliedSignal is now known as Honeywell.)

2.2.1 Technology Description (AlliedSignal, 1996)

The ICB™ technology combines a patented high surface area media (foam) with a support matrix to maximize the distribution of water and air throughout the bioreactor. In addition, reactor medium is coated with activated carbon, which is deposited by a patented method that promotes regeneration. Figure 2.2.1 is a process flow diagram of AlliedSignal's ICB™ technology. As shown on Figure 2.2.1, the technology consists of a multi-chambered reactor vessel filled with patented media. Wastewater is mixed with nutrients and the pH is adjusted prior to entering the reactor. Air is blown into the reactor through air diffusers, and exhausted from the reactor near the point where treated water effluent is discharged. Wastewater is pumped over and under baffles to promote biodegradation in the reactor vessel. According to AlliedSignal, the ICB™ technology requires relatively little space, has relatively lower O&M costs, and minimizes production of sludge.

2.2.2 Available Performance and Cost Data (AlliedSignal, Not Dated)

The ICB™ technology has been demonstrated on a wide range of process wastes, including wastes from textile finishers, chemical manufacturers, wood treating facilities, and beverage/food processors. In addition, the ICB™ technology has been used to remediate a site with groundwater contaminated by chlorinated solvents.

AlliedSignal provided available data on the use of the ICB™ technology to treat hazardous constituents frequently identified at RCRA and Superfund sites, such as chlorinated solvents, including information about an AlliedSignal site in Southfield, Michigan, that had chlorinated solvent contamination in the groundwater. This five-acre site had housed a mechanical engineering laboratory that used trichloroethene (TCE) as a degreasing solvent. When the site buildings were demolished, the

groundwater was found to contain TCE, cis-1,2-dichloroethene (DCE), and vinyl chloride, at the concentrations shown below in Table 2.2-1.

**Figure 2.2.1: Process Flow Diagram for AlliedSignal's ICB™ Technology
(AlliedSignal, Not Dated)**

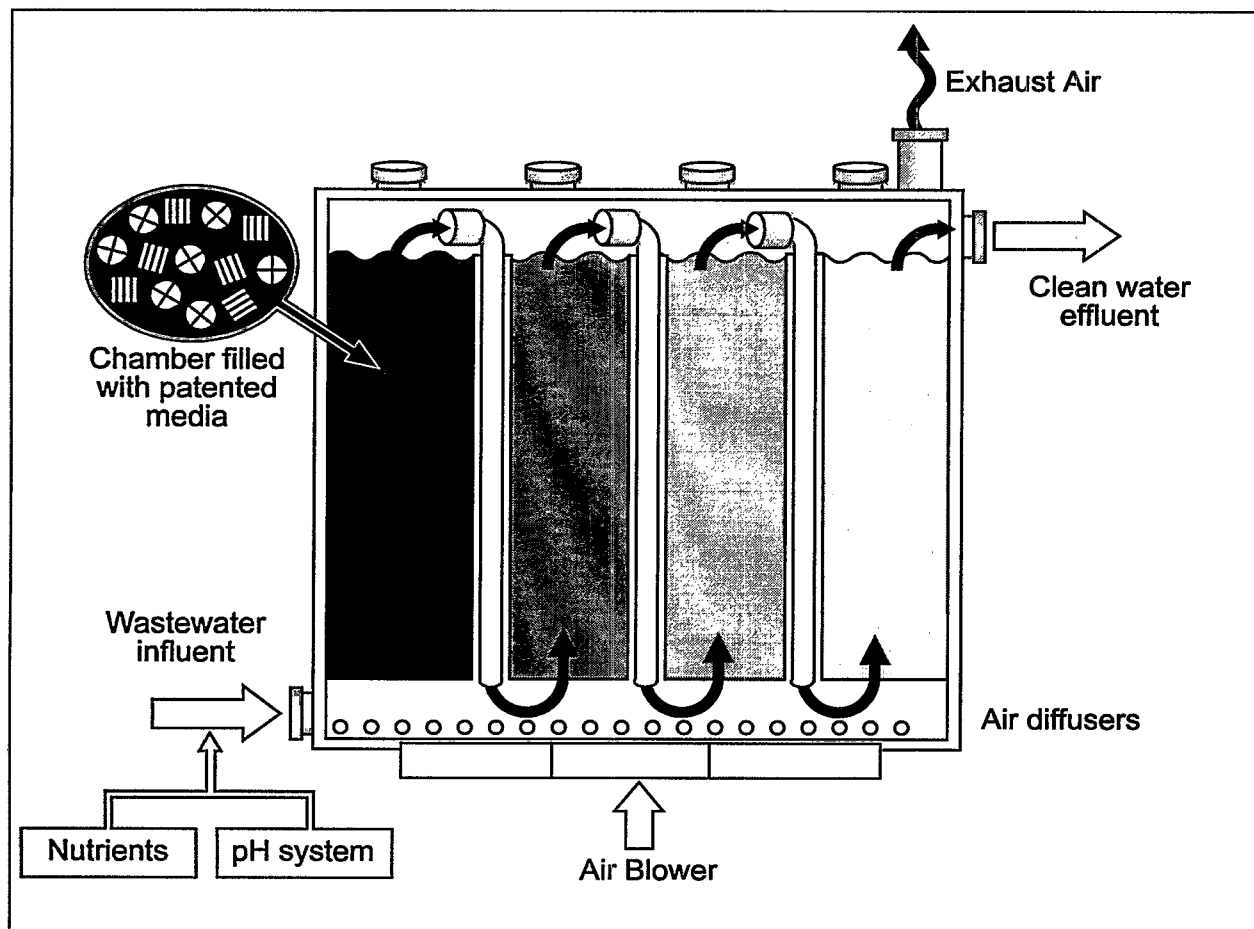


Table 2.2-1. Concentrations in Groundwater Prior to Treatment (AlliedSignal, Not Dated)

Parameter	Concentration (mg/L, except for pH)
TCE	26
cis-1,2-DCE	1.5
Vinyl chloride	0.05
pH	6.8 - 7.2
TOC	8 - 27
NH ₃ -N	2.3 - 7.1
O-PO ₄	0 - 2.5

AlliedSignal performed a field demonstration of a combined anaerobic-aerobic bioremediation system, including use of an ICB™, to remediate the groundwater at this site. Figure 2.2-2 shows the bioremediation system used in this demonstration. As shown in Figure 2.2-2, AlliedSignal added molasses to the groundwater just prior to re-injection into the aquifer, to promote the anaerobic biodegradation of TCE to DCE and vinyl chloride. Groundwater was then extracted from the aquifer and treated above-ground in a 50-gallon anaerobic bioreactor, to which additional molasses was added, to further promote the anaerobic biodegradation of TCE to DCE and vinyl chloride. Effluent from the anaerobic bioreactor was then fed to an aerobic ICB™, to which oxygen and phenol were added, to promote the oxidation of DCE and vinyl chloride. Table 2.2-2 shows the concentrations of TCE, DCE, and vinyl chloride in this treatment system.

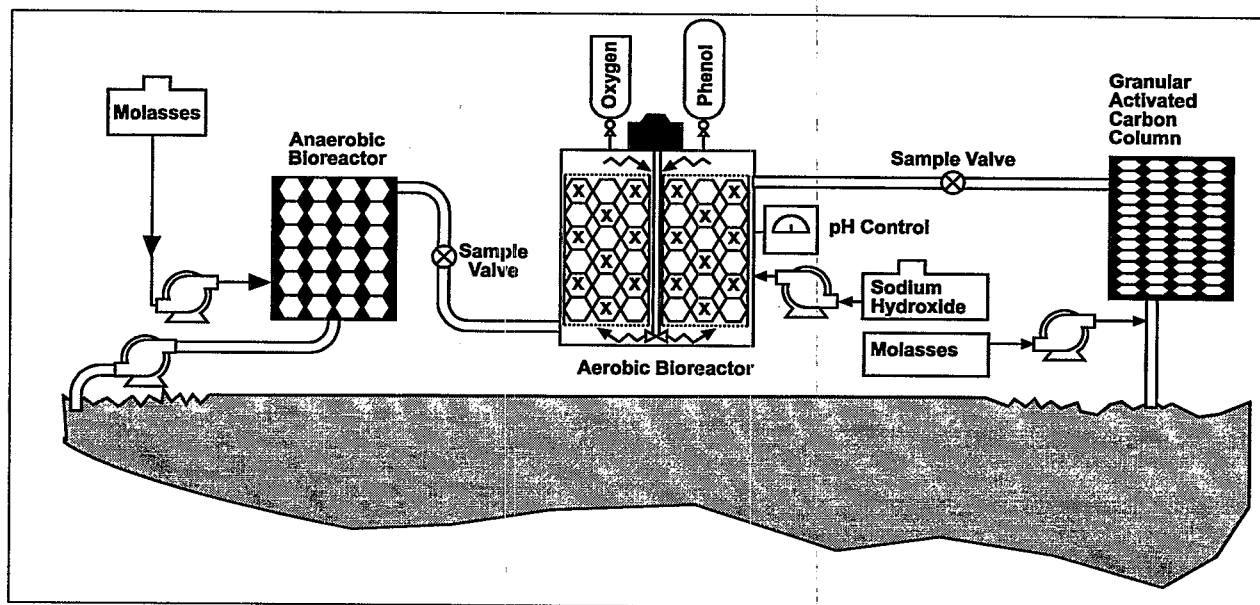
Figure 2.2.2: Bioremediation System Used in Field Demonstration (AlliedSignal, Not Dated)

Table 2.2-2. Summary of Constituent Concentrations in Southfield, Michigan Field Demonstration (mg/L) (AlliedSignal, Not Dated)

Constituent	Influent to Anaerobic Bioreactor	Effluent from Anaerobic Bioreactor	Effluent from Aerobic ICB TM Bioreactor
TCE	27.9	1.8	0.2
cis-1,2-DCE	7.4	19.8	0.4
Vinyl chloride	<0.1	0.6	<0.1

No information was provided about the cost for using the ICBTM technology at this site. However, AlliedSignal reported that costs for the ICBTM technology are competitive with other technologies on a life cycle basis.

In addition, AlliedSignal provided information about use of the ICBTM technology at several sites to treat industrial wastewater, such as the following:

- Burke-Parsons-Bowlby Corp., Central Pennsylvania, a wood treating facility
- Henkel Corporation, Castanea, Pennsylvania, a dye-intermediate facility

2.2.3 Results from ACWA Demonstration Testing (Dialogue on ACWA, August 1999, SRC, 1999)

As shown on Exhibit 1-1, AlliedSignal's ICBTM technology was selected for demonstration testing under the ACWA program. The system that was tested under the ACWA program consisted of an ICBTM unit followed by a catalytic oxidizer (catox) for treatment of off gases; catox was included because of the specific concerns related to potential emissions of chemical weapons. According to AlliedSignal, catox would not be required for all applications of the ICBTM technology.

The following data on the performance and cost of this technology were available from the ACWA program. The ICBTM technology was found to be capable of demilitarizing mustard-filled assembled chemical weapons but not nerve agent-filled weapons. It was found to be an "acceptably mature" process for mustard. The ACWA program data showed a concentration of 0.064 ng/m³ for dioxin/furan in the effluent from the catox unit (for processing of nerve agent HD). This was measured as toxicity equivalent quotient (TEQ, the international method of relating the toxicity of various dioxin/furan congeners to the toxicity of 2,3,7,8-TCDD). This value for dioxins and furans measured in the ACWA program was less than the emission standard for incinerators, which is 0.20 ng/m³ TEQ (40 CFR 63.1203).

Capital costs for the technology were found to be approximately 5 - 10% less than the costs for the "baseline" technology (incineration), depending on site-specific conditions. The ACWA Supplemental Report to Congress (September 30, 1999) concluded that the capital cost for ICBTM technology was approximately equal to that for incineration, given the uncertainties in the predicted values. O&M labor requirements were found to be comparable to those for the baseline technology, however insufficient

information was available to complete a comparison of total O&M costs to those for the baseline technology.

2.3 Commodore's Solvated Electron Technology

The Solvated Electron Technology (SET™) is a patented non-thermal process for the treatment of a wide range of organics including polychlorinated biphenyls (PCBs), pesticides, explosives and propellants, chemical warfare agents, chlorofluorocarbons (CFCs), and chlorinated solvents. The technology can be used to treat contaminants in a variety of matrices such as soils, sludges, sediments, oils, and shredded or crushed concrete and metals. The SET™ process also is used to treat solid surfaces including steel, wood, fiberglass, concrete, and rubber. The SET™ process is modular and can be used on a mobile or fixed-plant basis. The process is operated at a pressure that is higher than ambient, but relatively less than that used for the SCWO technologies. (Getman 1999, Financial News 1999, Commodore October 1998)

2.3.1 Technology Description

The SET™ process uses solvated electron solutions to reduce organic compounds to metals salts and the parent (de-halogenated) molecule. Solvated electron solutions, which are strong reducing agents, are formed by dissolving alkali or alkaline earth metals such as sodium or calcium in anhydrous liquid ammonia. Example byproducts from treating PCB-contaminated waste include petroleum hydrocarbons, sodium chloride, and sodium amide. (Commodore October 1998)

The SET™ process is part of Commodore's Solvated Electron System that is modular in nature and can be used in varying configurations to treat different types of wastes. All configurations include the SET™ treatment module. Depending on the type of waste and/or client-specific needs, front-end modules (for example, to remove water or extract specific contaminants prior to treatment), and back-end (post-treatment) modules (for example, to recycle ammonia, treat metals, or adjust pH) are added. (Getman 1999)

Figure 2.3-1 presents a diagram of the SET™ process for liquid wastes (including extracts from solid wastes). Solid sodium is warmed to a liquid state, then pumped to the solvator tank where it is dissolved in liquid anhydrous ammonia, forming the solvated electron solution. The solution is then pumped to the reactor vessel, where it is mixed with the waste and reacted to reduce the organics. After the reaction, the solution is transferred to an ammonia/matrix separator tank. The treated material is removed and sent to a storage vessel. The ammonia is transferred to another separator tank and heated to approximately 125°F to separate the ammonia vapor from water. The ammonia vapor is sent to a condenser and returned to the process. Offgases from the process are treated using carbon adsorption or a wet scrubber prior to discharge to the atmosphere or reused in the system. (Commodore October 1998, Getman 1999)

For solids, the material is first mixed with anhydrous liquid ammonia in a solids flow mixer reactor. The ammonia washes the contaminant from the substrate. Solid or molten sodium metal is then added and reacted with the organics. When the reaction is complete, the treated material is removed and sent to storage. The ammonia is returned to the process. Wet sludges may require a water removal step prior to treatment. (Commodore October 1998, Getman 1999)

Advantages and potential limitations identified by Commodore for this technology are summarized in Table 2.3-1.

Figure 2.3.1: Process Flow Diagram for Commodore's SET™ Process for Liquid Wastes (Modified from Teledyne-Commodore, Not Dated)

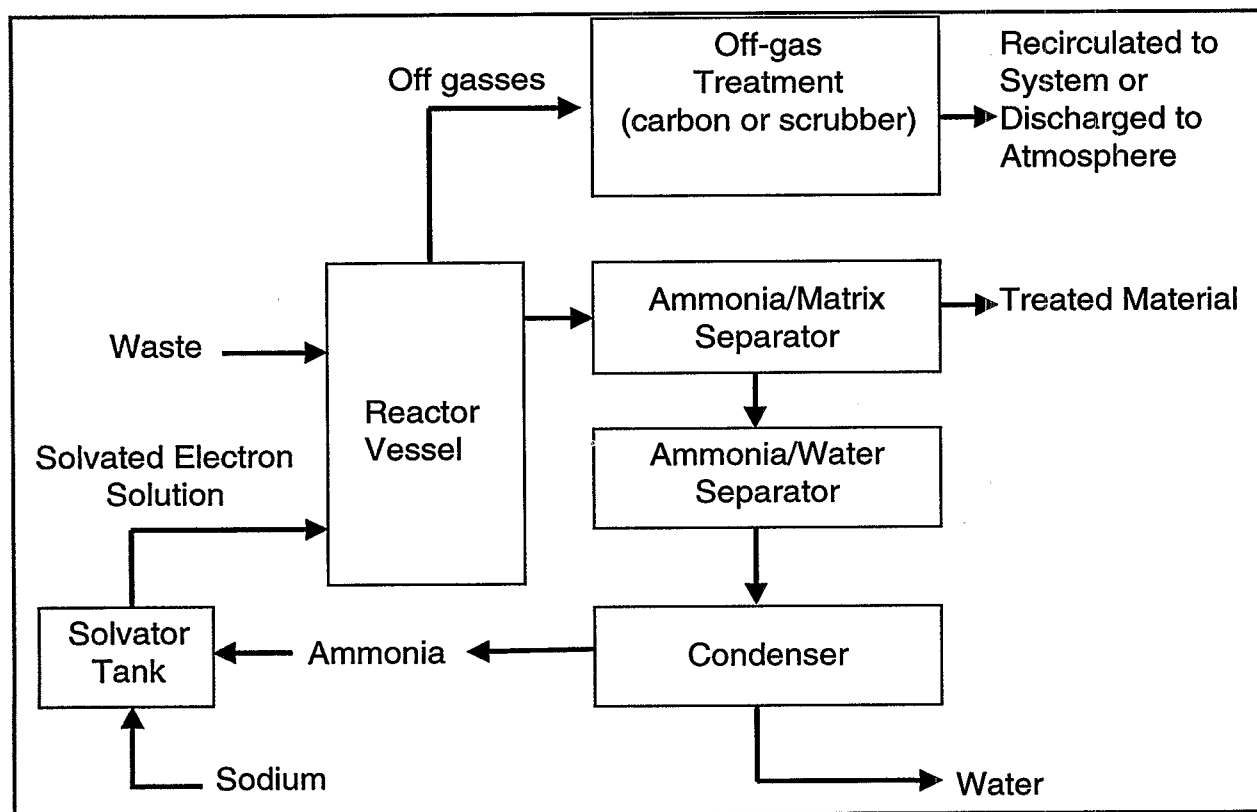


Table 2.3-1. Advantages and Potential Limitations of Commodore's SET™ Process (Commodore October 1998, Getman 1999)

Advantages	Potential Limitations
<ul style="list-style-type: none"> - Applicable to a wide range of organics in a wide range of matrices - Non-thermal process; effective as an alternative to incineration for PCBs, pesticides, chemical weapons and agents, and other organics - Only raw materials required are anhydrous ammonia and an alkali or alkaline earth metal which are commodity chemicals - Reaction byproducts are metals salts and the dehalogenated parent compound (no toxic intermediates) 	<ul style="list-style-type: none"> - Applicable only to matrices that can be penetrated by liquid ammonia; some solids, such as metal, concrete, and wood, must be crushed or shredded prior to treatment - Material with high water content (wet sludges) are usually dewatered prior to treatment

2.3.2 Available Performance and Cost Data

The SETTM process has been tested (laboratory and pilot-scale/field demonstrations) on a wide range of organic compounds in a variety of matrices (described above), and is currently being evaluated for full-scale application at several sites. For example, at a naval facility in Hawaii, the SETTM process is being evaluated for the remediation of 10,000 cubic yards of PCB-contaminated soil. On a full-scale basis, Commodore received a nationwide permit from EPA to use SETTM to treat PCBs, as an alternative to incineration. Commodore recently completed the construction of a commercial PCB processing plant (10 tons/day). In addition, Commodore has constructed a scaled-up version of a SETTM process unit, the L1200, capable of processing 66 pounds/hour of waste. The unit is currently in operation at Redstone Arsenal and is scheduled for commercial operation in the near future. (Getman 1999, Commodore October 1998).

Table 2.3-2 presents data provided by Commodore on the results of tests of wastes that may be found at Superfund and RCRA sites. Detailed performance data were also provided for studies of the SETTM process to treat PCBs at a New York utility and at the New Bedford Harbor (Sawyer Street) Superfund site in Massachusetts. In addition, Commodore provided more detailed performance and cost data about two pilot-scale studies of the SETTM process to treat PCBs and pesticides in various matrices, one at Port Hueneme, California and one at Commodore's facility in Marengo, Ohio. While extensive data also were provided for the treatment of chemical agents, these are not described for the purposes of this report.

Table 2.3-2. Summary of Performance Data on the SETTM Process by Contaminant and Matrix Type - Superfund and RCRA Wastes (Getman 1999)

Contaminant/ Matrix	Matrix Specifics	Scale/Location	Results (mg/kg)		
			Pre-treat	Post-treat	% Reduction/ DRE
PCBs - Soil	sand, clay	Pilot/Harrisburg PA	777	< 1	NR
	sand, silt, clay	Pilot/Los Alamos, NM	77	< 2	NR
	sand, silt	Pilot/NY	1250	< 2	NR
	sand, silt, clay	Pilot/Monroe, LA	8.8	< 1	NR
PCBs - Surfaces	stainless steel	Laboratory	NR	NR	99.999
	capacitor foil - aluminum	Laboratory	NR	NR	99.4
	Mylar	Laboratory	NR	NR	99.4
	charcoal	Laboratory	NR	NR	99.98
	ground corn cobs	Laboratory	NR	NR	99.7
PCBs - Oil	used motor oil	Pilot	23,339	< 1	NR
	transformer oil	Pilot	509,000	20*	NR

Table 2.3-2. Summary of Performance Data on the SET™ Process by Contaminant and Matrix Type - Superfund and RCRA Wastes (Getman 1999) (continued)

Contaminant/ Matrix	Matrix Specifics	Scale/Location	Results (mg/kg)		
			Pre-treat	Post-treat	% Reduction/ DRE
	mineral oil	Pilot	5,000	< 0.5	NR
	hexane	Pilot	100,000	0.5	NR
Dioxins/Furans - Oil	waste oil	Pilot/McCormick and Baxter site, Stockton, CA	dioxin - 418.5 furans - 14.1	dioxin - 0.0023 furans - 0.0013	NR
Pesticides - Soil	soil	Pilot/Barbers Point, HI	DDD - 200 DDT - 180 DDE - 69	DDD - < 0.02 DDT - < 0.02 DDE - < 0.02	NR
	soil	Pilot/Dahlgren, VA	DDD - 9 DDT - 1.6 Dieldrin - 15	DDD - < 0.02 DDT - < 0.02 Dieldrin - < 0.02	NR
CFCs	Various CFCs, HFCs, halons	Pilot	NR	NR	99.99
PAHs- pure	Pure compounds	Laboratory	1.99 - 2.01	ND - 0.39	99.98 - 99.999
Explosives - soil	soil	Laboratory/soil from Los Alamos	HMX - 1,600 RDX - 3,580 DNB - 9.6	HMX - 0.03 RDX - 0.03 DNB - 0.03	99.9999 99.99999 99.99

* - Sodium feed was insufficient
NR - not reported

The more detailed performance information provided by Commodore on the SET™ process is summarized below. Cost data provided by Commodore are based on studies of scaled-up versions of batch and continuous units.

New York State Utility PCB Spill

Soil at a utility site in New York was contaminated with PCBs (1,200 mg/kg) as a result of a spill. Other contaminants in the soil included small amounts of polycyclic aromatic hydrocarbons (PAHs), and metals (lead and mercury). Commodore performed a treatability study of the contaminated soil using SET™. PCB concentrations in the treated soil were 1.4 mg/kg (a reduction of > 99.88%). Following pH adjustment, the soil was returned to the site. Data on pre-treatment and post-treatment concentrations in the soil are presented below. (Getman 1999)

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

Contaminant	Pre-Treatment (mg/kg)	Post-Treatment (mg/kg)
Arochlor 1260	1,200	1.4
Pyrene	1.8	ND
Phenanthrene	1.4	ND
Mercury	0.21	0.08
Lead	433	267

ND - not detected

New Bedford Harbor (Sawyer Street) Superfund Site

A demonstration-scale test of the SETTM process was performed at this Superfund site to treat PCB-contaminated river sediments. The sediments were first washed with diisopropylamine (by the Ionics RCC B.E.S.T. TM process) to produce an oil concentrate containing PCBs at 32,800 mg/kg, dioxins/furans at 47 mg/kg, and metals including lead at 73 mg/kg. The concentrate was treated using the SETTM process. The treated concentrations were 1.3 mg/kg for PCBs and 0.012 mg/kg for dioxins/furans. In addition, metals were removed during the transport of liquid ammonia from the reactor vessel and recovered from the ammonia recycling unit for fixation and disposal. Data on pre-treatment and post-treatment concentrations in the sediments are presented below. (Getman 1999)

Contaminant	Pre-Treatment (mg/kg)	Post-Treatment (mg/kg)
PCB	32,800	1.3
Dioxin/Furan	47	0.012
Mercury	0.93	0.02
Lead	73	0.20
Selenium	2.5	0.20
Arsenic	2.8	0.10

Port Hueneme

Treatability tests of the SETTM process were conducted at Port Hueneme using the Commodore Mobile Disposal Unit 2 (CMDU2). The CMDU2 is fully contained in a mobile trailer and is designed to treat PCBs and pesticides. The process is operated under pressure (up to 200 psig) to maintain the ammonia as a liquid and can treat solids and liquids (see process description above). The process was tested on wastes, including PCB-contaminated oil, PCB-contaminated soil, PCB-contaminated activated charcoal, PCB-contaminated water, and pesticide-contaminated soil. Samples were shipped to an off-site laboratory for analysis. The results are summarized below. (Commodore October 1998)

Contaminant	Matrix Specifics	Pre-treatment (mg/kg)	Post-treatment (mg/kg)
PCB-Oil	Waste oil spiked with PCB arochlor from a transformer	160,000 - 410,000	< 1
PCB-Soil	PCB-contaminated soil from Port Hueneme - Site 22	777 - 931	< 4.55 - < 20*

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

Contaminant	Matrix Specifics	Pre-treatment (mg/kg)	Post-treatment (mg/kg)
	PCB-contaminated soil from Navy Public Works Center, Guam	0.83	11.4 - 12.4**
PCB-Activated Charcoal	PCB-contaminated charcoal from a solvent recovery operation	518	< 1 - < 0.03
PCB-Water	Water spiked with PCB arochlor from a transformer	3,100	< 0.00053 - < 0.00061
Pesticide-Soil	Pesticide contaminated soil from NAS Dahlgren, VA	DDD - 3.9 DDE - 0.9 DDT - 1.6 Dieldrin - 15 Chlordane - 1.6	DDD - < 0.02 DDE - < 0.02 DDT - < 0.02 Dieldrin - < 0.02 Chlordane - < 0.02
	Pesticide contaminated soil from NAS Barber's Point, Pearl Harbor	DDD - 170 - 240 DDE - 50 - 69 DDT - 160 - 180 Chlordane - 52 - 81	DDD - < 0.02 DDE - < 0.02 DDT - < 0.02 Chlordane - < 0.02

* - Interference problems increased method detection limits

** - Reactor vessel contained residual contamination from prior run; although initial field screen indicated soils contained more than 50 mg/kg PCBs, laboratory tests showed the soil to contain little PCBs

Marengo Ohio Tests

According to Commodore, because of the issues encountered with the Port Hueneme tests on PCB-contaminated soil (the interference and the low-level of PCBs in the sample, as well as no on-site laboratory to allow fast-turnaround results for use in modifying system parameters), additional treatability testing was performed at Commodore's facility in Marengo, Ohio. Soils from the same areas as used for the Port Hueneme study (PCB-contaminated soil from Site 22 at Port Hueneme, and pesticide contaminated soil from Barber's Point, Pearl Harbor) were used. The results are presented below. (Commodore October 1998) The Marengo Ohio tests also were identified as a completed SITE demonstration test.

Contaminant	Source	Pretreatment (mg/kg)	Post-treatment (mg/kg)
PCB-Soil	Port Hueneme	PCBs - 120 - 183	PCBs - 0.43 - 1.7
Pesticide-Soil	Barbers Point	DDD - 263 - 512 DDE - 197 - 362 DDT - 920 - 1,620 Dieldrin - ND Chlordane - 123 - 156	DDD - ND - 0.135 DDE - 0.172 - 5.55 DDT - ND - 0.072 Dieldrin - ND - 0.0002 Chlordane - 0.15 - 0.68

Cost Data - Projected Costs for Full-Scale Operation

Commodore provided the following information on projected full-scale costs of the SET™ process, based on scale-up studies of batch and continuous units to treat solid and liquid wastes. (Commodore October 1998)

Total treatment cost per ton	\$400 - 800
Reagent (sodium) cost per pound	\$1.15 - 1.85
Sodium usage	4% - 8% (by weight)
Ammonia cost per ton	\$2 - 5
Capital/maintenance costs per ton	\$80 - 100

2.3.3 Results from ACWA Testing

As discussed in Exhibit 2-1, Teledyne-Commodore LLC was one of the technology service providers included in the ACWA program. Teledyne-Commodore's system includes the SETTM process that is offered for use by non-ACWA clients by Commodore. The SETTM process is used to demilitarize chemical weapons containing chemical agents, and explosive compounds and fuses (energetics). The chemical agent or energetic material is first removed from the munition, then destroyed using the SETTM process (described above) followed by chemical oxidation. Off gases from the chemical oxidation systems are sent through carbon filters, then reused as supplemental fuel in the system. An ammonia recovery system is used to capture and recycle all ammonia. Treated materials are stabilized and sent off-site to a RCRA permitted landfill, along with spent carbon and other solids generated by the process. (Teledyne-Commodore, undated).

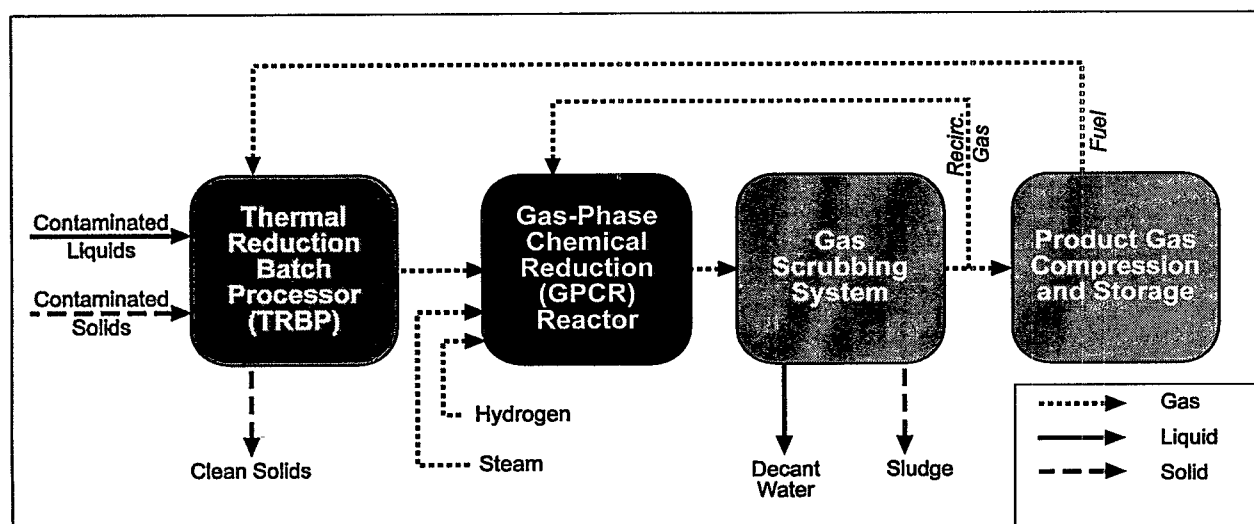
Funding limitations resulted in three of the six ACWA technologies being demonstrated in FY99, with the remaining four (including the SETTM process) being demonstrated in FY00.

2.4 Eco Logic's Gas Phase Chemical Reduction Technology

The patented Eco Logic Gas Phase Chemical Reduction (GPCR) technology uses hydrogen gas at temperatures of 850 to 900 °C to reduce organics including chlorinated hydrocarbons, such as polychlorinated biphenyls (PCBs), dioxins, pesticides, and polycyclic aromatic hydrocarbons to hydrogen chloride and methane. The absence of free oxygen in the reactor minimizes dioxin formation and water acts as a hydrogen donor and heat transfer agent to enhance the reaction. The technology is suitable for treating organics in a variety of matrices, including soil, sediment, sludges, high strength oils, watery wastes (contaminated water), and bulk solids. Eco Logic has two portable demonstration units and one stationary facility (in Australia). (Eco Logic 1999, EPA 1994, Woodland, 1999)

2.4.1 Technology Description

Figure 2.4.1 is a general process flow diagram for a GPCR application. The GPCR reactor is the main component of the system. Other components are added to the system, including various waste preparation and feed mechanisms and offgas treatment, depending on the type of waste treated. For example, a Thermal Reduction Batch Processor (TRBP) is used to volatilize contaminants from solid materials or to volatilize contaminated liquids prior to injection into the GPCR reactor. Liquid wastes also may be injected directly into the GPCR reactor through atomizing nozzles (contaminated liquid is preheated in a Liquid Waste Preheater System (LWPS) prior to being injected into the reactor). System outputs include clean water, treated solids, and product gas. All outputs are stored and analyzed for regulatory compliance prior to off-site disposal or reuse. (Eco Logic 1999, EPA 1994, Woodland, 1999)

Figure 2.4.1: Process Flow Diagram for Eco Logic's GPCR Technology (Eco Logic, 1999)

Steam (from the steam heater) and hydrogen (bottled or from a hydrogen generation system) are added to the waste in the reactor, where they form a gas mixture. The gas mixture is heated by 18 vertical radiant tube heaters in the reactor to a temperature of 850 to 900 °C. The products of the reaction, which takes less than one second to complete, include hydrochloric acid (HCl) and methane from the reduction of chlorinated organics, and lighter hydrocarbons such as methane and ethene from the reduction of straight-chained and aromatic hydrocarbons. Gas from the reactor is sent to a Gas Scrubbing System where the gas is quenched, then passed through a scrubber to remove HCl, particulates, and water. The gas exiting the scrubber contains excess hydrogen, lighter hydrocarbon reduction products such as methane, and a small amount of water vapor. A portion of the gas (hydrogen-rich) is reheated to 500 °C and recirculated back into the reactor. The remainder of the gas from the scrubber is sent to product gas compression and storage where it serves as a supplementary fuel in the process or is compressed and stored for later use in other parts of the process. The principal waste stream is the scrubber residuals which include decant water (which is recycled into the process) and scrubber particulate (which is stored and analyzed and then retreated or shipped off-site for disposal.) (Eco Logic 1999, EPA 1994, Woodland, 1999)

2.4.2 Available Performance and Cost Data

The GPCR technology has been tested at laboratory and demonstration scales on a wide variety of organic wastes and materials. Eco Logic has portable demonstration systems in Japan and at Eco Logic's Rockwood, Ontario facility. The process was evaluated by EPA's SITE program at a demonstration conducted at Bay City's Middleground Landfill. On a commercial basis, Eco Logic currently operates one commercial full-scale stationary system in Australia, and completed a full-scale demonstration of the system at a General Motors facility in St. Catharines, Ontario.

Eco Logic provided available data on the use of GPCR technology to treat hazardous constituents frequently identified at RCRA and Superfund sites, for full-scale treatment (Table 2.4-1), pilot/demonstration-scale testing (Table 2.4-2) and laboratory-scale testing (Table 2.4-3) including the SITE

demonstration. More detailed data were also provided in the Applications Analysis Report from the SITE Program demonstration. These results are summarized below. In addition, Eco Logic provided data on the destruction of chemical warfare agents; however, these data are not included for the purposes of this report.

Table 2.4-1. Summary of Full-Scale GPCR Operations (Eco Logic 1999, Woodland, 1999)

Location	Type of Waste	Summary of Operations/Results
Kwinana, Western Australia (routine operations)	Pesticides (DDT) PCB-contaminated wastes	Began operating in May 1995, initially treating DDT residuals owned by the Department of Agriculture of Western Australia. In November 1995, began processing PCB-contaminated wastes for government and industrial clients. Currently processing wastes for a variety of clients. Results: DRE of $\geq 99.9999\%$ based on regulatory testing during DDT and PCB treatment.
Kwinana, Western Australia (hexachlorinated waste)	Hexachlorobenzene (HCB) wastes	The testing involved three trial runs on a total of eight tonnes of HCB waste. Results indicated a 98% reduction in the mass input to the TRBP. In excess of 99.9999% of the HCB and chlorobenzene present in the waste were volatilized in the TRBP and swept to the reactor for destruction. Destruction efficiency measurements indicated at least 99.9999% destruction of HCB and total chlorobenzene.
General Motors St. Catherine, Ontario	PCB-contaminated material, including concrete, soil, electrical equipment, high-strength oil, watery wastes, and miscellaneous process wastes	In the fall of 1997, a full-scale demonstration was conducted at this site to treat approximately 1,000 tons of PCB-contaminated material. Results: DREs of $\geq 99.99999\%$; routine testing confirmed compliance with all regulatory and discharge criteria.

Table 2.4-2. Summary of Pilot/Demonstration-Scale GPCR Operations (Eco Logic 1999)

Demonstration	Contaminants/ Matrix	Results
Hamilton Harbour, Ontario	PCB - Sediment	First demonstration of the mobile SE5 unit in 1991 to treat harbour sediment contaminated with PCBs at concentrations up to 300,000 mg/kg (dry weight). Results: PCB DRE $\geq 99.9999\%$
Bay City Michigan (SITE Program)	PCB-contaminated water; high-strength PCB oil; and PCB-contaminated soil	Demonstration of the SE5 unit under EPA's SITE Program. PCB concentrations in untreated water/oil was 4,000 mg/kg. Results: PCB in water/oil - DRE $\geq 99.9999\%$ PCB in soil - DE 94% to 98% See description below for more detail
Warren County Landfill Soil	PCB-contaminated soil	Three tests runs were conducted on PCB-contaminated soil from the landfill. Results: PCBs in treated soils were ND with a DRE ≥ 99.99999

Table 2.4-3. Summary of Laboratory-Scale Testing of GPCR (Eco Logic 1999, EPA 1999)

Testing Type	Contaminants/Matrix	Results		
		Pre-Treatment (mg/kg)	Post-Treatment (mg/kg)	DRE (%)
Research and Development	PCB-contaminated soil and sediment	7.3 - 1,200	ND - 0.00097	Stack Gas Not Analyzed
Commercial Client Treatability Studies	PCB - Capacitors	360,000	0.00008 - 0.0033	Stack Gas Not Analyzed
	PCB - Canadian Electric Capacitors	75,000 - 76,000	0.003 - 0.037	Stack Gas Not Analyzed
	Hexachlorinated Waste	Hexachlorobenzene (66%) Hexachlorobutane (17%) Hexachloroethane (2%)	Not Applicable	99.9999
	Dioxins/Furans - Great Lakes Harbour Sediment	Dioxins/furans - 2 PAHs - 0.80	Dioxins/furans - ND PAHs - 0.0058	Stack Gas Not Analyzed
Contaminated Harbor Sediment	Eight sediment samples contaminated with PCBs, PAHs and other compounds; two samples spiked with trichlorobenzene (Hamilton Harbour, Sheboygan Harbour, Thunder Bay Harbour);	Trichlorobenzene - 1,000	Not Provided	99.9999, 100.0000
		PCBs - 5 - 7	Not Provided	99.99 - 99.999
		PAHs	Not Provided	99.99
		Chlorophenols	Not Provided	99.999 - 100

The following is additional performance data from the SITE Program demonstration.

SITE PROGRAM DEMONSTRATION (EPA 1994)

A SITE demonstration of the Eco Logic GPCR process was conducted in October and December 1992 at the Bay City Middleground Landfill in Michigan. Objectives of the demonstration included demonstrating at least 99.9999% DRE for PCBs, at least 99.99% destruction efficiency for PCE, ensure that no dioxins or furans were formed, evaluate air emissions, and perform an overall evaluation of the process. PCB-contaminated oil, water, and soil from the landfill were used for the demonstration. The first part of the demonstration involved a series of shakedown tests to establish optimum operating parameters. Data were collected on the composition of the principal process streams, reactor grit, scrubber residuals, reformed gas, and boiler stack emissions. Following system optimization, two tests were run - the first on 2.9 tons of wastewater contaminated with PCBs at 3,757 mg/kg and PCE at 3,209 mg/kg; the second on 0.2 tons of waste oil contaminated with PCBs at 254,000 mg/kg (25%) and PCE at 6,203 mg/kg. The key operating parameters (Table 2.4-4) and the results of the evaluation (Table 2.4-5) are summarized below.

Table 2.4-4. Summary of Average Operating Conditions During SITE Demonstration (EPA 1994)

Equipment	Parameter
Reactor	Temperature (°C) - 892 to 933 Pressure (in. water) - 1.8 Residence time (sec) - 6.1 to 8
Scrubber	Inlet temperature (°C) - 527 to 546 Outlet temperature (°C) - 32 to 33 Water pH - 8.78 to 9.32
Recirculating fan	Differential pressure (in. water) - 7.8 to 11.6 Flow rate (cfm) - 110 Gas pressure (in. water) - 6.5
Vaporizer	Temperature (°C) - 148.3 to 149 Pressure (psi) - 51.4 to 51.8

Table 2.4-5. Summary of Key Results from SITE Demonstration (EPA 1994)

Parameter	Summary Results
PCB DRE	99.9999 - 99.99999%
PCE DE	99.99%
Dioxin/furans	No net formation
HCl emissions	0.659 - 0.807 mg/dscm; 109.1-197.8 mg/hr; 99.98% removal; met MDNR permit conditions
PIC emissions	Benzene - 73 - 113 ug/dscm - exceeded MDNR permit conditions
Other air emissions	Except for benzene, met MDNR permit conditions
Scrubber residuals	Met TSCA level for PCBs (3 ppb)

According to Eco Logic, the costs associated with treatment of various waste types is dependent on a number of factors including contaminants, waste matrix, site configuration, schedule, and scale of system. Eco Logic has stated that now that the technology is at a commercial scale, the costs for the technology are better known than they were at the time of the SITE demonstration in 1994. The specific cost for treatment is calculated on a site-by-site basis, considering these factors, and includes the execution of a non-disclosure statement. Therefore, Eco Logic was not able to provide specific full-scale costs for the technology.

Information developed by EPA in 1994 on projected costs for full-scale operation of the technology are presented below. In addition, a total cost and a unit cost were provided. A range of costs was calculated based on 60%, 80%, and 90% utilization factors to address unforeseen job conditions. Because of the limited data, the cost estimates presented may range in accuracy from +50% to -30%. These costs are presented in Table 2.4-6.

Table 2.4-6. Projected Costs for Three Scenarios Using GPCR Technology, Based on 1994 SITE Demonstration (EPA 1994)

Item	Costs (\$)		
	60% Utilization (250 Days)	70% Utilization (214 Days)	80% Utilization (188 Days)
Actual throughput	500 tons	500 tons	500 tons
Site preparation	127,400	127,400	127,400
Capital equipment	50,400	44,700	37,800
Start-up/mobilization	109,950	104,150	98,350
Labor	564,000	498,000	431,000
Supplies	110,000	106,000	103,000
Utilities	10,500	10,500	10,500
Residuals	2,500	2,500	2,500
Maintenance	4,000	3,500	3,000
Demobilization	20,000	20,000	20,000
Total costs	998,750	916,750	833,550
Cost per ton at actual throughput	2,000	1,850	1,670
Cost per ton at targeted throughput	670	620	550

The largest cost component was operational labor (more than 50%), followed by site preparation (15%), supplies (12%), and start-up/mobilization (12%). According to EPA, considering the effect of labor costs on the price and the relative constancy in scale-up of the other categories, there is a potential to reduce unit cost for commercial scale-up by increasing equipment capacity. Larger capacity would decrease process time and therefore decrease labor costs.

In addition, no analytical cost were included in these estimates, as they would be dependant on local regulatory requirements and/or client specifications. EPA notes that analytical requirements could significantly affect costs.

2.4.3 Results from the ACWA Testing Program

Funding limitations resulted in three of the six ACWA technologies being demonstrated in FY99, with the remaining four (including GPCR) being demonstrated in FY00.

2.5 Foster Wheeler's Supercritical Water Oxidation Technology

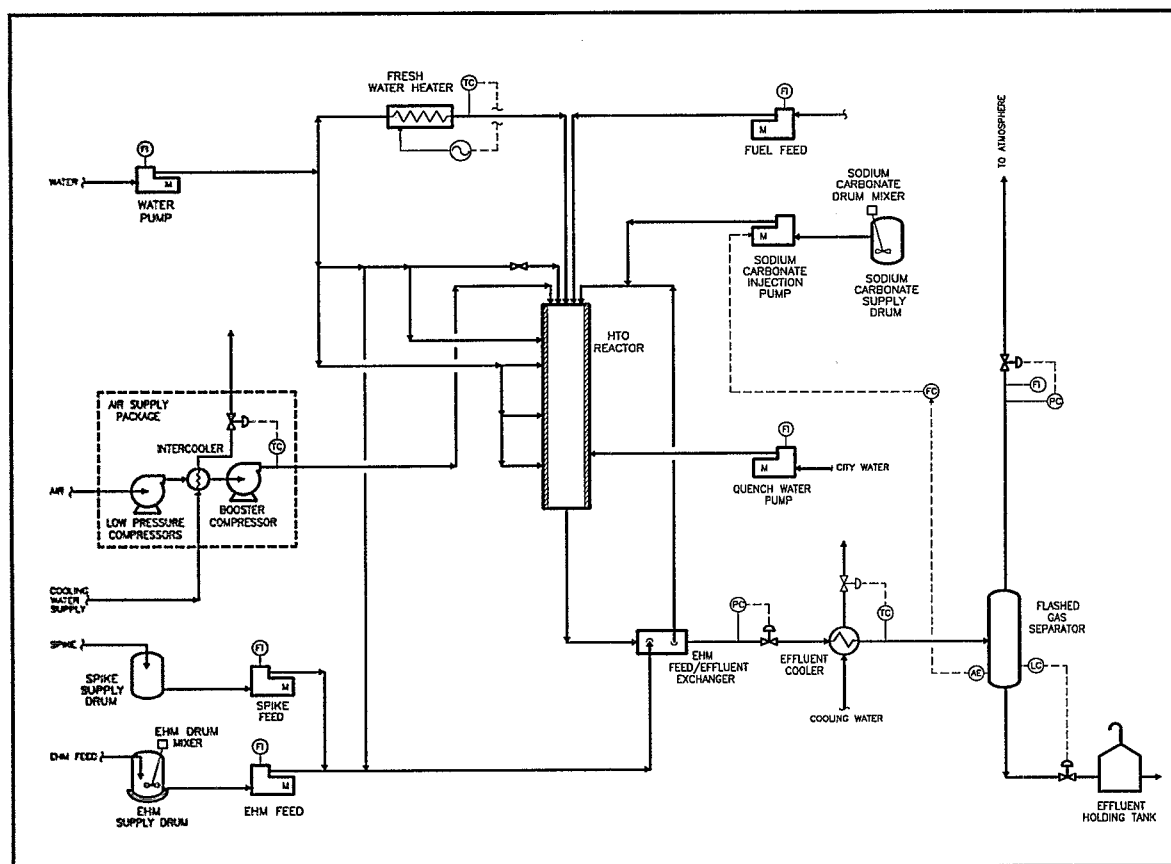
The Foster Wheeler Supercritical Water Oxidation (SCWO), also known as hydrothermal oxidation, treats aqueous organic wastes at elevated temperature and pressure [above the critical point of water (374°C and 22.1 Mpa)]. Organic wastes become highly soluble at conditions above the critical point of water, and the aqueous wastes functions as a fuel in an oxidation reaction. The process has been used in several demonstration testing programs, but has not yet been implemented at the full-scale (see discussion about Pine Bluff under Section 2.5.2). The Foster Wheeler SCWO differs from the General Atomics SCWO technology (discussed in Section 2.6). The Foster Wheeler technology uses a transpiring wall reactor design that is intended to protect the liner of the pressure vessel from salt deposition and corrosion and provide a thermal and corrosion barrier for the pressure vessel; the General Atomics technology uses a solid wall reactor design.

2.5.1 Technology Description (Foster Wheeler, Not Dated)

Figure 2.5.1 is a process flow diagram of Foster Wheeler's SCWO technology, as tested recently for the U.S. Navy. As shown on Figure 2.5.1, hazardous material is mixed with water and fuel, and then pressurized and partially heated prior to feeding to the reactor. The hazardous material and fuel are oxidized in the reactor in the presence of air, raising reactant temperature and leading to more efficient oxidation. Depending on the feed material, sodium carbonate may be added to the hazardous material feed to neutralize acids. Effluent from the reactor is quenched with water to dissolve salts and to reduce effluent temperature. After quenching, the pressure of the effluent is reduced and the effluent (treated material) is discharged. A gas/liquid separator may be used to separate the effluent in some applications.

Reaction by-products from a SCWO process depend on the components of the waste. Organic materials produce carbon dioxide and water; nitrogen compounds principally produce nitrogen and a relatively smaller amount of nitrogen oxides; halogens produce their corresponding halogen acids; phosphorus produces phosphoric acid; and sulfur produces sulfuric acid. These acids are neutralized in the reactor or immediately downstream, producing inorganic salts.

Figure 2.5.1: Process Flow Diagram of Foster Wheeler's SCWO Process (Ahluwalia, 1999)



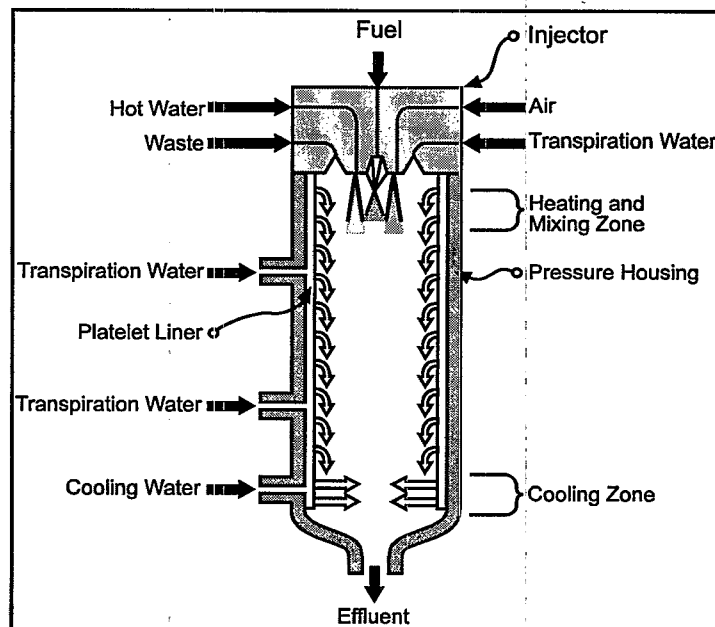
Important waste characteristics for use of a SCWO process include the heating value; major component chemical composition; and other waste properties such as fluid specific gravity, fluid viscosity, percent solids, and solids size distribution. Wastes that have a heating value below a certain level will require external heating or mixing with a higher heating value fuel or waste, while wastes with a higher heating value will require dilution. The major component chemical composition is required to estimate oxygen requirements, which impacts the design of the gaseous effluent system. Large suspended solids in the feed may be removed by filtration methods prior to the SCWO unit. Wastes with organic solids will likely require size reduction pretreatment steps such as shredding, cutting, or grinding.

Potential limitations for use of a SCWO process include concerns about corrosion and plugging of reactors. Knowledge of the halogen, sulfur, and phosphorus content of the waste, as well as the chemical form of these elements, is important because of their potential to contribute to excessive corrosion in process equipment or lines.

Figure 2.5.2 shows a schematic of the transpiring wall reactor used by Foster Wheeler. The reactor uses transpiring wall platelet technology developed by GenCorp Aerojet. The transpiring wall is based on the use of platelet devices, which provides an intricate circuitry that meters and repeatedly divides a flow

stream into thousands of small injection pores, and that forms a protective boundary layer to inhibit salt deposition and corrosion. Platelet devices are made by diffusion bonding a stack of thin plates (or "platelets"), each of which is etched with flow control passages. Platelets differ from porous liners by providing for precise flow controls. Platelets may be manufactured from a variety of materials, including Inconel (alloys of nickel and chromium) and platinum.

Figure 2.5.2: Transpiring Wall Reactor Used in Foster Wheeler's SCWO Technology (Foster Wheeler, Not Dated)



2.5.2 Available Performance and Cost Data (Foster Wheeler, August 1999)

Foster Wheeler has performed testing of its SCWO technology on excess hazardous materials typically found aboard naval vessels for the Office of Naval Research. In addition, the U.S. DOE has discussed testing of the SCWO technology for mixed hazardous wastes, including organic liquid waste of aromatic hydrocarbons and mercury; nonchlorinated solvent waste with RCRA hazardous metals and radionuclide surrogates; solid waste of paper, cloth, and plastic; and highly chlorinated cutting oil.

Foster Wheeler provided available data from recent testing performed for the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR) on excess hazardous materials (EHM) typically found aboard Navy vessels. Three types of EHM were tested in this effort. Table 2.5-1 summarizes the composition of the EHM, the operating conditions for each test, and the results, as shown under effluent concentrations. The goals identified for the tests were to achieve Total Organic Carbon (TOC) concentrations in the effluent of less than 10 ppm. As shown on the table, these goals were achieved for all three types of feed materials.

**Table 2.5-1. Summary of DARPA/ONR Testing for Foster Wheeler SCWO
(Foster Wheeler, August 1999)**

Parameter	EHM 1: 1% Polychlorotrifluoroethene/99% kerosene, by weight	EHM 2: 10% 1,1,1-trichloroethane/90% kerosene, by weight	EHM 3: Photo Simulant Solution *
Hours	25.8	30	16
Mass Waste Feed (lbs)	2,475	3,554	3,000
Pressure (psig)	3,425	3,500	3,475
Temperature, average reactor (°F)	1,250	1,260	1,230
Air Flow Rate (lb/hr)	1,350	1,600	1,300 - 1,700
Waste Throughput (lb/hr)	80	102	72 - 207
Effluent O ₂ (%)	3 - 4	2-4	2 - 4
Effluent CO (ppm)	1 - 20	0 - 2	50 - 120
Effluent TOC (ppm)	1.4	1.4	2

* Photo Simulant Solution, by weight:

85.4% water
10.7% ammonium sulfite
1.9% sodium sulfite
1.0% potassium sulfite
0.4% acetic acid
0.5% pentanol

Foster Wheeler is also in the process of testing their SCWO system for the U.S. Army for destruction of pyrotechnic smoke-producing mixtures, most of which contain organic dyes, however data are not yet available from the results of that testing. At Pine Bluff Arsenal, Foster Wheeler is testing a full-scale unit for destruction of these smokes and dyes. According to Foster Wheeler, after testing, the unit will be used by the arsenal to destroy their inventory of smokes and dyes. (Ahluwalia, November, 1999)

2.5.3 Results from ACWA Demonstration Testing

Funding limitations resulted in three of the six ACWA technologies being demonstrated in FY99, with the remaining four (including Foster Wheeler's SCWO technology) being demonstrated in FY00.

2.6 General Atomics' SCWO Technology

The General Atomics' SCWO technology, also known as hydrothermal oxidation, treats organic wastes at elevated temperature and pressure [above the critical point of water (374°C and 22.1 Mpa)]. Organic wastes become highly soluble at conditions above the critical point of water, and the aqueous wastes

functions as a fuel in an oxidation reaction. The process has been used in several demonstration testing programs, including those for destruction of neat and hydrolyzed chemical agents, shipboard wastes, solid propellants, biomass and human wastes, mixed wastes, and industrial wastewaters, but has not yet been used at the full-scale. General Atomics is currently designing a full-scale system for the Newport Chemical Agent Disposal Facility at Newport, Indiana, with construction slated to begin in early 2000. This system is anticipated to consist of three reactors (2 on-line, 1 spare), each of which will be 15 ft long and 10-inch diameter, and lined with platinum for this application, the secondary treatment of caustic-hydrolyzed VX. The General Atomics SCWO technology differs from the Foster Wheeler SCWO technology (discussed in Section 2.5). The General Atomics technology uses a solid wall reactor design with a corrosion-resistant liner to protect the pressure vessel wall from salt deposition and corrosion; the Foster Wheeler technology uses a transpiring wall reactor design.

The General Atomics' SCWO technology is covered by 10 U.S. patents, including those for organic gasification, processing methods for the oxidation of organics in supercritical water, a method and apparatus for solids separation in a wet oxidation process, SCWO with overhead effluent quenching, and use of zirconium oxide ceramics for surfaces exposed to high temperature water oxidation environments.

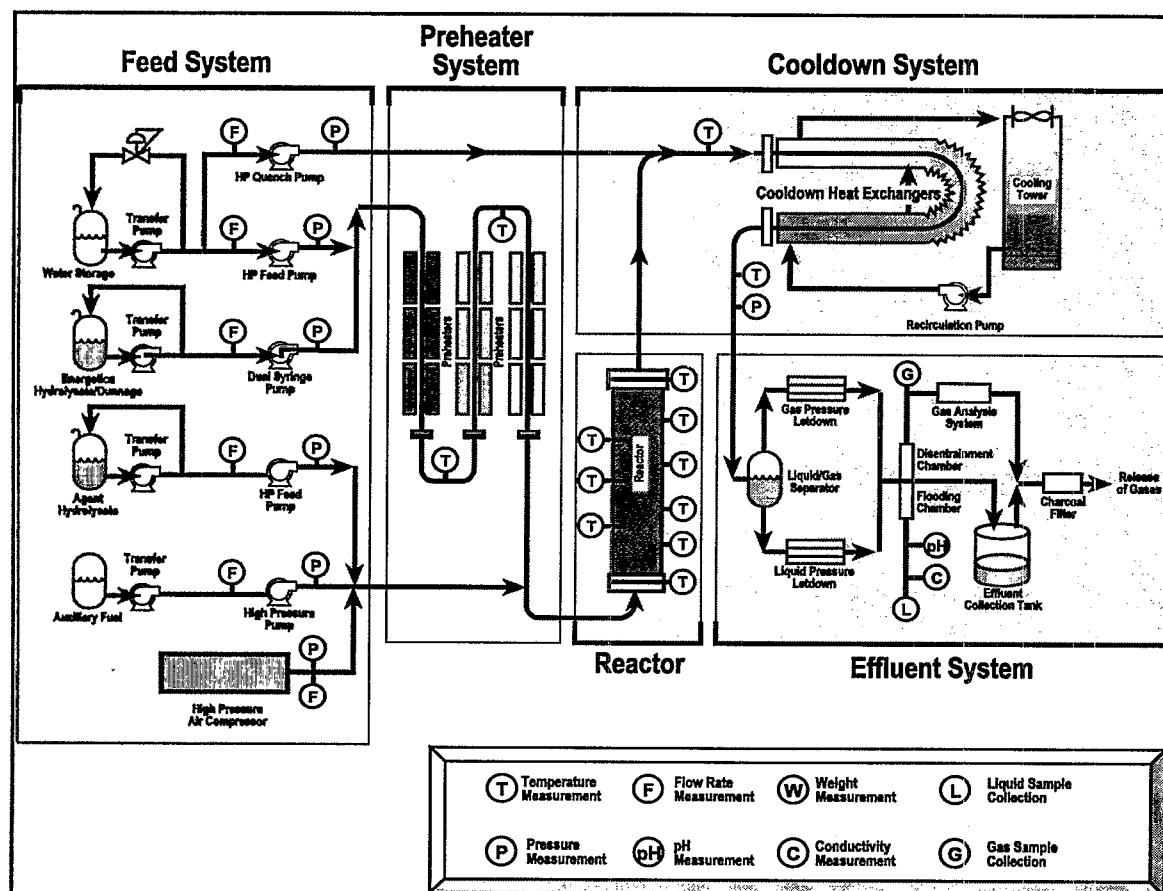
2.6.1 Technology Description (General Atomics, Not Dated)

Figure 2.6.1 is a process flow diagram of General Atomics' SCWO technology, as tested recently for the ACWA program. As shown on Figure 2.6.1, the General Atomics' system consists of a reactor and separate subsystems for feed, preheat, cooldown, and effluent treatment. Organic waste solution (shown as hydrolysate) is pumped through preheaters (if required) and then mixed with auxiliary fuel and high pressure air. The mixture is fed to a reactor where organic materials are converted to carbon dioxide, water, and inorganic salts or acids. Reactor effluent is cooled using heat exchangers and sent to the effluent treatment system. In the effluent treatment system, gases are separated from liquids and further treated, depending on project requirements, with a charcoal filter. Liquids are discharged to an effluent collection tank.

Reaction by-products from a SCWO process depend on the components of the waste. Organic materials produce carbon dioxide and water; nitrogen compounds principally produce nitrogen, and a relatively smaller amount of nitrous oxides; halogens produce their corresponding halogen acids or salts; phosphorus produces phosphoric acid or phosphate salts; and sulfur produces sulfuric acid or sulfate salts.

Potential limitations for use of a SCWO process include concerns about corrosion and plugging of reactors. Knowledge of the halogen, sulfur, and phosphorus content of the waste, as well as the chemical form of these elements, is important because of their potential to contribute to excessive corrosion in process equipment or lines. General Atomics indicated that pretreatment steps may be necessary to feed these compounds. Deposition of salts and pyrolytic chars may result in plugging problems or added cleaning requirements. Salt deposition may be a concern if salts are present in the feed or if acids in the feed are neutralized. General Atomics uses its patented engineering designs, including selection of materials, to help overcome the corrosion and plugging concerns that can occur with a SCWO process.

Figure 2.6.1: Process Flow Diagram for General Atomic's SCWO Technology (General Atomic, August 1999)



2.6.2 Available Performance and Cost Data (General Atomic, October 1997)

General Atomic indicated that the following types of wastes have been treated in their SCWO systems: organic chemicals, inorganic substances, and complex feeds. These have included the following common Superfund and RCRA waste site constituents: carbon tetrachloride, chlorinated dibenzo-p-dioxins, chlorobenzene, DDT, hexachlorobenzene, polychlorinated biphenyls, tetrachloroethene, tributyl phosphate, trichloroethene, and trifluoroacetic acid.

General Atomic provided available data from recent testing performed for the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR) on excess hazardous materials (EHM) typically found aboard Navy vessels. Fourteen types of EHMs were tested in this effort. Table 2.6-1 summarizes the composition of the EHMs, the operating conditions (system parameters) for each test, and the results. The goals identified for the testing program were to process 100 lb/hr of EHM (1,000 lb/day), produce nontoxic effluents that meet all regulatory requirements, have a compact unit size, have very high reliability with minimal maintenance, and be fully automated with a simple operator interface. No specific goals for Organic Carbon concentrations in the effluent were identified, however there was a target of 99.99% DRE. As shown on the table, these goals were achieved for all types of feed materials.

Table 2.6-1. Summary of DARPA/ONR Testing for General Atomics' SCWO (General Atomics, November 1999)

		Fluorochlorocarbon	Chlorinated Solvent	Glycol / Antioxidant	Motor Oil	Gray Water	Black Water	Paint Waste	Lube Oil	Photographic Solution	Hydraulic Fluid	Category II (Org.)	Category II (Aq.)	Category III (Org.)	Category III (Aq.)
System Parameters	Steady-State Time (hr)	30	30	30	30	30	30	27	30	30	30	12	15	15	15
	Waste Feed Rate (lb/hr)	102	107	191	101	136	135	136	102	105	107	106	118	103	103
	Reactor Temperature (C)	638	638	648	648	648	648	648	657	658	658	658	658	658	658
	Reactor Pressure (psig)	3250	3430	3430	3430	3430	3430	3430	3430	3430	3430	3430	3430	3430	3430
	Cooling Water (gpm)	95	91	91	84	96	96	95	93	91	91	96	96	93	96
	Reactor Residence Time (s)	10	11	11	10	15	15	13	11	15	11	10	15	11	15
	Airflow Rate (lb/hr)	1690	1660	1650	1670	1650	1650	1690	1710	1650	1710	1720	1650	1660	1650
	Feed Water Flow Rate (lb/hr)	721	703	644	744	70	70	322	622	70	569	685	70	548	70
	Quench Water Flow Rate (lb/hr)	2240	2290	2360	2020	1710	2460	2780	3020	2430	3120	2120	3090	3000	3290
	Kerosene-Startup (lb)	11	9	8	8	15	14	6	11	15	13	7	14	9	20
	Kerosene-Steady State (lb/hr)	0	0	0	0	41	45	0	0	40	21	0	35	0	40
	Kerosene-Shutdown (lb)	8	--	--	--	5	--	--	6	10	20	8	6	5	9
	Startup Time (hr)	1.03	0.95	0.73	0.6	1.03	1.03	0.43	1.25	1	--	0.6	1.02	0.85	1.08
	Shutdown Time (hr)	1	0.95	--	--	--	0.68	--	--	--	--	--	0.18	0.97	0.77
	Fully Automated Operation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes ¹	Yes	Yes	Yes	Yes
Results	Waste Carbon DRE (%)	>99.998	>99.998	>99.997	>99.998	>99	>99	>99.997	>99.997	>99.7	>99.997	>99.998	>99.97	>99.997	>99.97
	Organic Carbon DRE(%)	>99.998	>99.998	>99.997	>99.998	>99.997	>99.996	>99.997	>99.997	>99.994	>99.997	>99.998	>99.995	>99.997	>99.995
	HTO effluent TOC (ppm)	<0.5 ²	<0.5	<0.5 ³	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Mineral Acids Produced (%)	0.6	8.2	0	0	0	0	0	5.5	7.7	29	4.9	0.04	7.2	0
	CO (ppm)	< 2	< 2	< 2	2	< 2	< 2	< 2	< 2	< 2	< 2	< 0.2	0.2	<2	<2
	Phenols (ppm)	<0.03	<0.03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2
	Chromium (ppm)	<0.003	<0.003	<0.001	<0.001	<0.002	<0.001	0.007	0.003	0.004	0.005	0.003	0.003	<0.003	<0.003
	Volume Reduction (%)	100	~100	100	~100 ⁴	~100 ⁴	~100 ⁴	52	~100 ⁴	~100 ⁴	100	~100	~100	~100 ⁴	~100 ⁴

¹ The system was operated with single-button control for all steps except one feed ramping step. There was not time for a pretest with this class of feed, so this ramp step was completed manually. The ramp went smoothly and the control logic will easily be modified to accommodate this class of feed automatically.

² City water was used (without filtration to remove organic carbon) for the first test only. The quench fluid mixes with the reactor effluent without exposure to the high temperatures of the reactor, and city water contains 2.6 ppm of organic carbon. The reactor effluent/quench combined TOC was 1.3 ppm. If this value is adjusted for the TOC entering with the quench water, the reactor effluent TOC was <0.5 ppm.

³ The quench fluid contains 2.6 ppm of organic carbon. The reactor effluent/quench combined TOC was 2.7 ppm. If this value is adjusted for the TOC entering with the quench water, the reactor effluent TOC was <0.5 ppm.

⁴ The amount of solids in the effluent were too small for an accurate measurement.

Performance data also are available for use of General Atomics' SCWO systems for the treatment of solid propellants, biomass and human wastes, mixed wastes, and industrial wastewater. For example, under contract to the Air Force Armstrong Laboratory at Tyndall AFB, General Atomics constructed a pilot plant for the destruction of solid rocket propellants. This plant was operated at a test site in Utah and demonstrated greater than 99.99% removal of TOC.

2.6.3 Results from ACWA Demonstration Testing (Dialogue on ACWA, August 1999, SRC, 1999)

As shown on Exhibit 1-1, General Atomics' SCWO technology was selected for demonstration testing in 1999 under the ACWA program. The system that was tested under the ACWA program consisted of the process shown in Figure 2.6-1.

The following data on the performance and cost of this technology were available from the ACWA program. The General Atomics' SCWO technology was found to destroy constituents in agent and energetic hydrolysate to levels that were generally below detection limits, and to have demonstrated a level of maturity feasible for full-scale implementation, with some reservation about the maturity of the SCWO process. The ACWA program data showed a concentration that ranged from 0.025 - 0.100 ng/m³ for dioxin/furan in the off-gases from the SCWO. This was measured as toxicity equivalent quotient (TEQ, the international method of relating the toxicity of various dioxin/furan congeners to the toxicity of 2,3,7,8-TCDD). This value for dioxins and furans measured in the ACWA program was less than the emission standard for incinerators, which is 0.20 ng/m³ TEQ (40 CFR 63.1203).

Capital costs for the technology were found to be approximately 5 - 10% less than the costs for the "baseline" demilitarization technology (incineration), depending on site-specific conditions. The ACWA Supplemental Report to Congress (September 30, 1999) concluded that the capital cost for SCWO technology was approximately equal to that for incineration, given the uncertainties in the predicted values. O&M labor requirements were found to be comparable to those for the baseline technology; however insufficient information was available to complete a comparison of total O&M costs to those for the baseline technology.

2.7 Startech's Plasma Waste Converter Technology

Startech's Plasma Waste Converter (PWCTM) technology is an electrically-driven machine that produces an intense field of radiant energy to treat solid, liquid, and gaseous organic and inorganic compounds or materials. Plasma is discharged within a chamber in a continuous arc to produce temperatures of 30,000 °F and higher, operating at normal atmospheric pressure.

Recently, Startech announced that it had signed a contract for the sale of a 10-ton per day commercial Plasma Waste Converter system to process chemical industry hazardous waste in Taiwan. In addition, Startech reported that it has sold a PWCTM system to a company in South Africa.

2.7.1 Technology Description (Startech, March 2000)

Figure 2.7.1 illustrates Startech's PWCTTM technology. As shown on Figure 2.7.1, the technology consists of a plasma torch inside a vessel containing mixed bulk gases. Plasma feed gas (air, argon, carbon dioxide, or nitrogen) is fed in and product gas removed at the top of the vessel, and chemical agent (or other contaminated media) and steam are fed through the side. Inorganic portions of feed materials typically remain in the PWCTTM as scrap metal and non-leachable silicate glass. The vessel is cylindrical and refractory-lined. Argon (later replaced with carbon dioxide and then nitrogen) was used as the feed gas in the ACWA PWCTTM demonstration at Aberdeen Proving Ground.

Figure 2.7.1: Startech's PWCTTM Technology (Startech, March 2000)

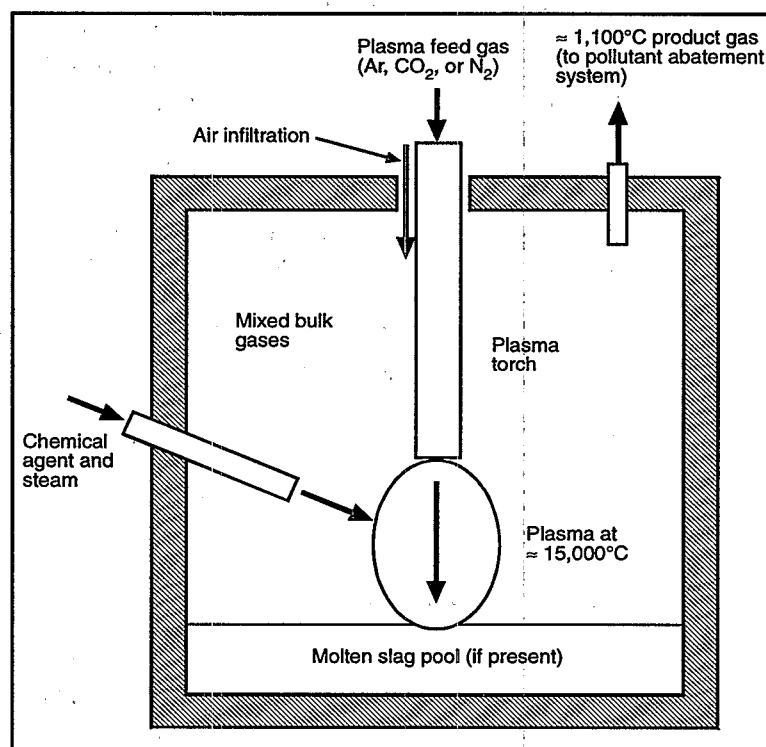


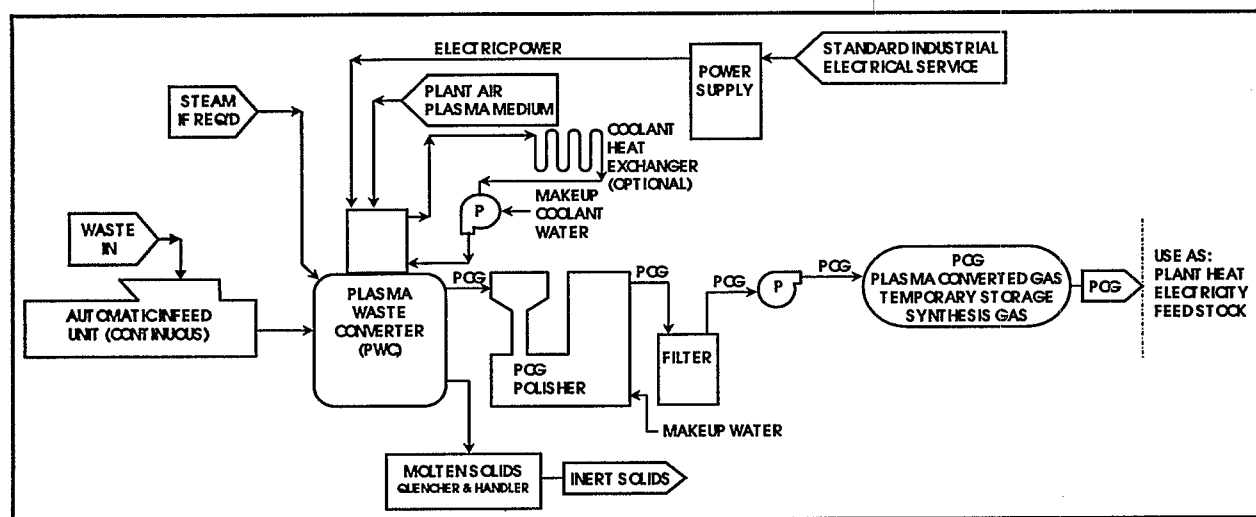
Figure 2.7.2 is a process flow diagram of Startech's PWCTTM system, as recently tested for the ACWA program. As shown on Figure 2.7.2, the Startech system consists of a feed system, plasma torch, PWCTTM, Plasma Converted GasTM (PCGTM) gas polisher, HEPA filter blower and plasma torch cooling system. A feed stream of solids, liquids, and/or gases is remotely introduced into the refractory-lined steel vessel. A water-cooled plasma torch, positioned above the incoming feed stream, generates the plasma field from plant air traveling past the torch head. The high temperature plasma gas in the oxygen-deprived vessel creates an environment for the conversion of waste materials to PCGTM (composed primarily of H₂ and CO, with low concentrations of CO₂ and N₂), metals, and non-leachable silicate glass. If the waste feed composition has insufficient quantities of oxygen, steam is introduced to achieve the

proper stoichiometric balance. When sufficient quantities of glass and metals have accumulated in the PWC™, the vessel can remotely tilt to allow the molten materials to pour out through an access door and into a charge car. The system operates under a slight negative pressure (-2" to -0.5" of H₂O, gage) to evacuate the PCG™ from the PWC™ to the gas polisher.

The Gas Polisher System consists of several process units in series that process the PCG™ to produce clean-burning synthesis fuel for beneficial reuse. The first two process units are venturi scrubbers. These units cool (quench) the gases as well as remove suspended particulate from the raw PCG™. The next process unit is the Gas Polisher Tower. The polishing chamber is an updraft, counterflow vertical tower filled with polymeric packing to provide adequate surface area for mass transfer. This stage removes acid gases from the PCG™. Water used by the venturis and tower are collected in the Gas Polisher Water Reservoir and recirculated continuously by a centrifugal pump. Caustic is automatically added to the reservoir to maintain a pH range of 7 to 8.5. A HEPA filter is located after the gas polisher for final removal of particulate.

The final mechanical component is the Induced Draft Fan (ID Fan). This unit creates the draw that pulls the PCG™ through the treatment train and maintains the negative pressure in the PWC™ vessel. The ID Fan incorporates a motor with a variable frequency drive (VFD) to regulate fan RPM and upstream pressure. Clean, high BTU value PCG™ exiting the blower is ducted to the point of use or disposal.

Figure 2.7.2: Startech's PWC™ Process Flow Diagram (Startech, March 2000)



2.7.2

Available Performance and Cost Data (Startech, March 2000)

The PWC™ has been tested at a scale of 100-200 pounds per hour on infectious medical waste, explosives in waste streams, solvent contaminated industrial process wastes, K045 spent carbon, lead contaminated soils and other waste streams. Full-scale plasma technology also is currently being used to vitrify ash from municipal solid waste combustors in Japan. The process produces synthesis fuel gas (PCG™), non-leachable silicate glass, scrap metal and gas polisher blowdown. Blowdown from the wet-scrubbing units of the gas polisher can be evaporated and the solids reintroduced into the PWC™ for

vitrification. Data from an analysis of PCG™ from the processing of hazardous and infectious medical waste, when the gas was used as a fuel, are provided in Table 2.7-1. This table shows that emissions of dioxins, furans, cadmium, lead, mercury, HCl, NO₂, SO₂, CO, and particulates are all lower than the identified standards. Data from an analysis of silicate stone from the processing of lead contaminated soil is provided in Table 2.7-2. This table shows that the concentration of lead in a TCLP extract was reduced from 310 mg/L in the soil to less than 0.75 mg/L in the silicate stone (product of PWC process).

Table 2.7-1. Emissions of Plasma Converted Gas from Processed Hazardous Medical Waste (Startech, March 2000)

Parameter	Emissions ^a Plasma Waste Converter	MOE REG 346 ^b Air Quality Standards	EPA Regulated Medical Waste Standards
PCDD TEQ (dioxin)	0.0000000024	0.00045	0.0006
PCDF TEQ (furan)	0.0000000090	0.00045	0.0006
Cadmium	0.0000415980	5.0	40.0
Lead	0.02254	10.0	70.0
Mercury	0.0000398660	1.5	550.0
HCl	0.65404	100.0	15.0
NO ₂	0.41730	500.0	250.0
Particulate	1.8737	No Standard Required	34,000.0
SO ₂	0.0188083	830.0	55.0
CO	None Detected	6,000.0	40.0

^a Maximum ground level concentrations
^b Max. permitted ground level concentrations
 MOE Ontario Ministry of the Environment
 PCDD Polychlorinated dibenzo-p-dioxins
 PCDF Polychlorinated dibenzofurans

HCl Hydrogen Chloride
 NO₂ Nitrogen Oxide
 SO₂ Sulfur Dioxide
 TEQ Toxicity Equivalent Quotient

Table 2.7-2. Composition of Silicate Stone from Processing of Lead Contaminated Soil (Startech, March 2000)

Parameter	Soil TCLP	Glass 1 TCLP	Glass 2 TCLP	Glass 3 TCLP
Date	1/12/96	1/24/96	1/24/96	1/24/96
As	<DL	<DL	<DL	<DL
Ba	8.80 mg/L	<DL	<DL	<DL
Cd	<DL	<DL	<DL	<DL
Cr	<DL	0.085 mg/L	<DL	<DL
Pb	310 mg/L	0.49 mg/L	0.73 mg/L	0.37 mg/L
Hg	<DL	<DL	<DL	<DL
Se	<DL	<DL	<DL	<DL
Ag	<DL	<DL	<DL	<DL
Total Solids	82.7%	--	--	--
Total C	58,000 mg/kg	--	--	--

DL detection limit

Startech reported that PWCTM processing costs for most wastes vary from \$0.07 to \$0.10 per pound. This figure includes labor, materials, utilities, consumables and capital depreciation. Potential revenues from the sale of process products are not considered. Startech also has a patented hydrogen separation process unit, StarcellTM, which isolates valuable pure hydrogen from the PCGTM produced when processing carbon-based wastes. Startech indicated that the hydrogen is valuable and can provide positive impact on processing economics.

2.7.3 Results from ACWA Demonstration Testing (Dialogue on ACWA, August 1999)

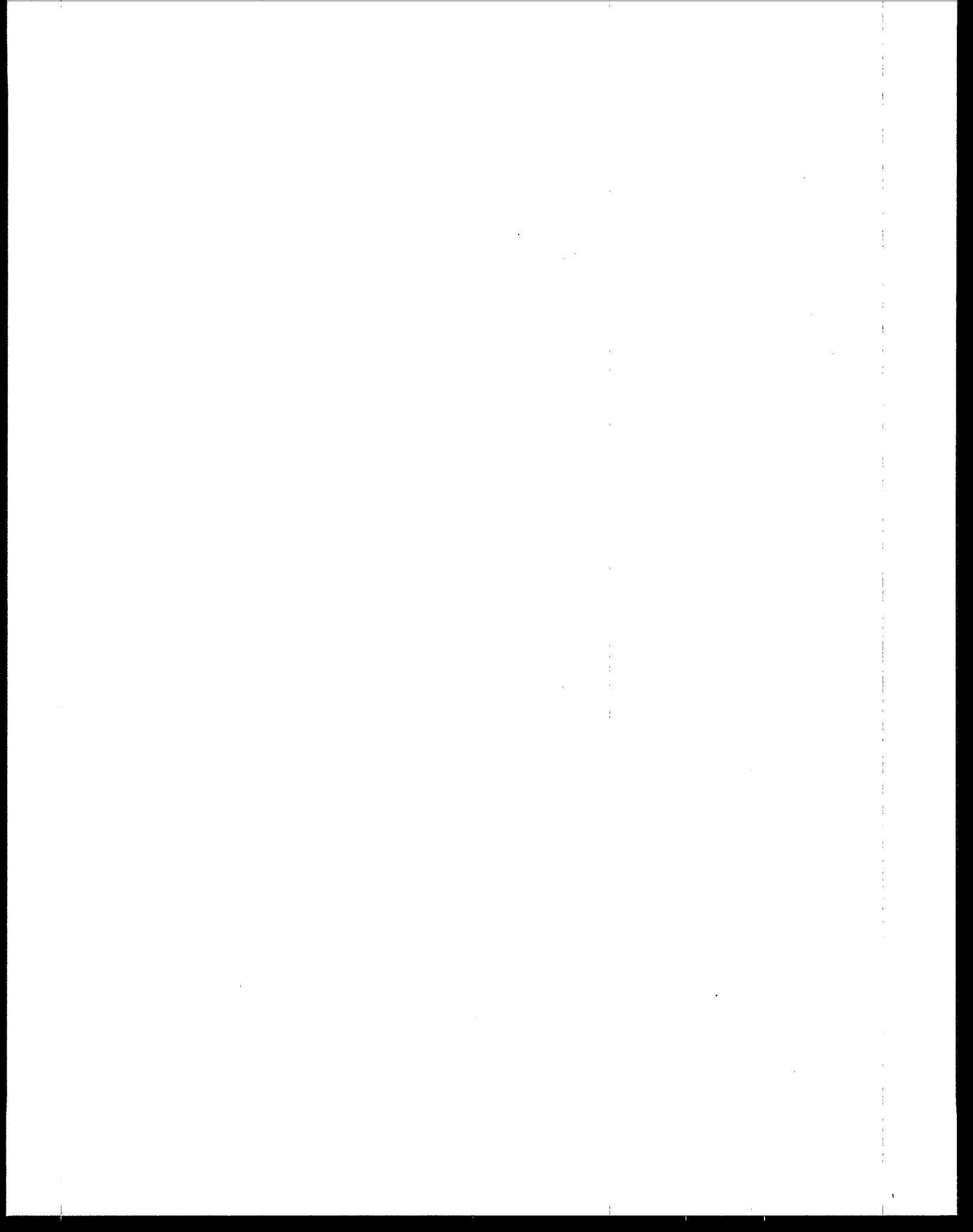
As shown on Exhibit 1-1, Startech's PWCTM was selected for demonstration testing in 1999 under the ACWA program. The system that was tested under the ACWA program is described above.

The following data on the performance and cost of this technology were available from the ACWA program. The Startech system was found to destroy agent simulant to >99.9999% and energetics to >99.9999%, however actual agent testing was not performed. Leakage of air into the PWCTM during the demonstration caused an excess of oxygen over the desired level, which caused the PCGTM to be composed primarily of carbon dioxide and water, rather than carbon monoxide and hydrogen, as had been planned. The effects from this and other operational concerns are discussed in the ACWA program Supplemental Report to Congress (September 30, 1999). In response, Startech claimed that the full capabilities and maturity of the PWCTM were not identified in the ACWA program. According to Startech, subsequent upgrades of the ACWA PWCTM system have led to reliable, full-scale commercial operations of that system.

The ACWA program data showed a concentration of 0.100 ng/m³ for dioxin/furan in the off-gases (for dunnage and HD hydrolysate processing). This was measured as toxicity equivalent quotient (TEQ, the

international method of relating the toxicity of various dioxin/furan congeners to the toxicity of 2,3,7,8-TCDD). This value for dioxins and furans measured in the ACWA program was less than the emission standard for incinerators, which is 0.20 ng/m³ TEQ (40 CFR 63.1203).

Capital costs for implementation of the technology for chemical demilitarization were found to be approximately equal to or 5% greater than the costs for the "baseline" technology (incineration), depending on site-specific conditions. The ACWA Supplemental Report to Congress concluded that the capital cost for PWCTM technology was approximately equal to that for incineration, given the uncertainties in the predicted values. O&M labor requirements were found to be 15 to 20% higher than those for the baseline technology, however insufficient information was available to complete a comparison of total O&M costs to those for the baseline technology.



3.0 POTENTIAL FOR APPLICATION OF ACWA TECHNOLOGIES TO TREAT RCRA WASTE STREAMS COMPARABLE TO ACWA WASTES

EPA evaluated the potential applicability of the seven ACWA technologies to treat RCRA wastes by identifying the ACWA technologies that are capable of treating RCRA wastes currently being treated by combustion and the ACWA technologies that are capable of treating organic wastes that have chemical structures similar to the ACWA wastes that were tested. The methodology and results from these analyses are presented below.

3.1 Applicability to Treating RCRA Wastes Currently Treated by Combustion

Six of the seven ACWA technologies — AEA's SILVER II™, Commodore's SET™ process, Eco Logic's GPCR, Foster Wheeler's SCWO, General Atomics' SCWO, and Startech's PWC™ — involve chemical oxidation, chemical reduction, and thermal processes that the providers indicate are capable of destroying a wide range of organics, including those currently treated by combustion. Because none of the ACWA technology firms provided data on treatment of specific RCRA-listed hazardous wastes, EPA evaluated the potential applicability of these technologies by examining the types and quantities of wastes that are treated by combustion technologies (combustion includes incineration in commercial and on-site/captive units, and in commercial kilns).

Available information on the types and quantities of RCRA wastes treated by combustion was obtained from EPA reports and from the Biennial Reporting System (BRS). As shown in Figure 3-1, from EPA's report "Assessment of the Potential Costs, Benefits, & Other Impacts of the Hazardous Waste Combustion MACT Standards: Final Rule" (July 1999), the total quantity of waste managed in combustion systems was 3,282,995 tons, based on data in the 1995 Biennial Reporting System (BRS). Table 3-1 shows that nearly one-third of the waste that is combusted originates in the industrial organic chemicals sector, and nearly one-eighth originates in the pesticides and agricultural chemicals sector, based on 1995 BRS data.

The cost of using incineration to treat hazardous wastes has been identified by EPA and by a national trade association representing commercial hazardous waste treatment facilities (the Environmental Technology Council - ETC). For example, in an economic analysis of an air emissions rule for hazardous waste combustors, EPA estimated the cost for treatment of wastes by incineration. Those results show that the cost for incineration vary based on the type of waste treated, as shown on Table 3-2. Table 3-2 shows that the costs for use of incineration varied from as low as \$70 per ton treated for relatively less contaminated wastes, to as high as \$1,281 per ton for relatively highly contaminated wastes.

The ETC provided the results from a survey of its member companies on the prices charged for incineration of various types of wastes in the second half of calendar year 1999. The results from the ETC survey, shown on Table 3-3, indicate that the price for commercial incineration of bulk pumpable sludges ranged from \$175 to \$1,500 per ton, and for bulk contaminated soils from \$375 to \$1,000 per ton. These are the only two types of waste for which ETC reported prices on a per ton basis. The prices for incineration of these two types of wastes are roughly comparable to the range of costs reported by EPA in the 1999 report cited above.

Figure 3-1: RCRA Waste Quantities Managed by Combustion Systems (EPA, 1999)

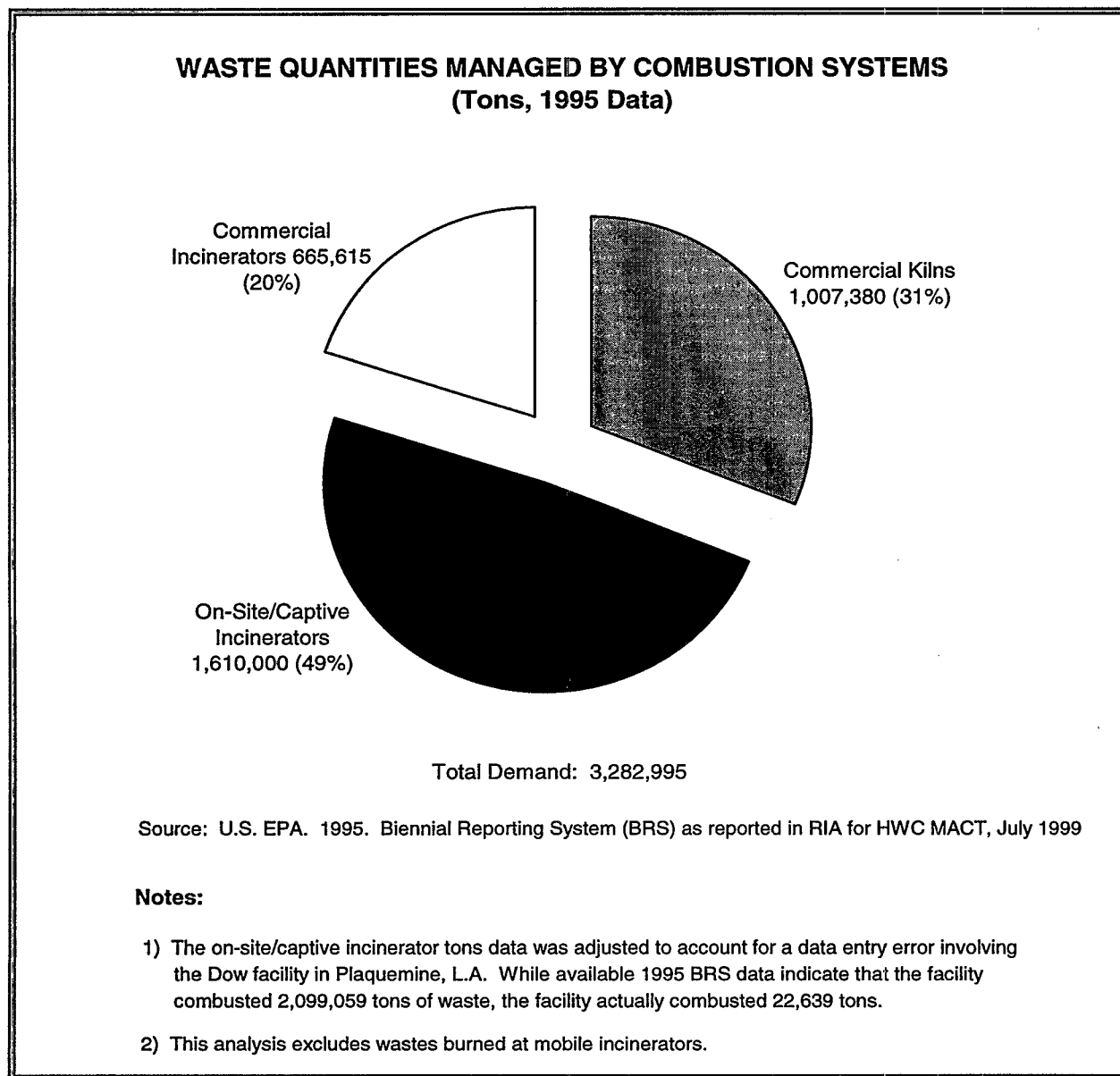


Table 3-1. Summary of Industrial Sectors Generating Combusted RCRA Wastes (EPA, 1999)

INDUSTRIAL SECTORS GENERATING COMBUSTED WASTE, 1995				
	SIC Code	Corresponding NAIC Codes	Quantity (tons)	% of Total Quantity
Industrial Organic Chemicals, N.E.C.	2869	32511, 325188, 325193, 32512, 325199	853,216	31.82
Pesticides and Agricultural Chemicals, N.E.C.	2879	32532	321,869	12.00
Business Services, N.E.C.	7389	51224, 51229, 541199, 81299, 54137, 54141, 54142, 54134, 54149, 54189, 54193, 54135, 54199, 71141, 561421, 561422, 561439, 561431, 561491, 56191, 56179, 561599, 56192, 561591, 52232, 561499, 56199	245,241	9.15
Organic Fibers, noncellulosic	2824	325222	190,209	7.09
Medicinal Chemicals and Botanical Products	2833	325411	157,520	5.87
Pharmaceutical Preparations	2834	325412	105,881	3.95
Plastics Materials and Resins	2821	325211	93,043	3.47
Petroleum Refining	2911	32411	92,023	3.43
Industrial Inorganic Chemicals, N.E.C.	2819	325998, 331311, 325131, 325188	64,826	2.42
Unknown	NA	NA	61,487	2.29
Nonclassifiable Establishments	9999	NA	46,108	1.72
Services, N.E.C.	8999	71151, 51221, 54169, 51223, 541612, 514199, 54162	30,585	1.14
Paints, Varnishes, Lacquers, Enamels	2851	32551	29,837	1.11
Cyclic Organic Crudes and Intermediates, and Organic Dyes and Pigments	2865	32511, 325132, 325192	29,667	1.11

Table 3-1. Summary of Industrial Sectors Generating Combusted Wastes (continued)

INDUSTRIAL SECTORS GENERATING COMBUSTED WASTE, 1995				
	SIC Code	Corresponding NAIC Codes	Quantity (tons)	% of Total Quantity
Air, Water, and Solid Waste Management	9511	92411	28,033	1.05
Photographic Equipment and Supplies	3861	333315, 325992	27,356	1.02
Scrap and Waste Materials	5093	42193	18,768	0.70
Synthetic Rubber (Vulcanizable Elastomers)	2822	325212	17,025	0.63
Special Warehousing and Storage, N.E.C.	4226	49312, 49311, 49319	14,914	0.56
Primary Aluminum	3334	331312	12,648	0.47
Chemicals and Chemical Preparations, N.E.C.	2899	32551, 311942, 325199, 325998	10,303	0.38
Sanitary Services, N.E.C.	4959	48819, 56291, 56171, 562998	10,089	0.38
Alkalies and Chlorine	2812	325181	9,567	0.36
Local and Suburban Transit	4111	485111, 485112, 485113, 485119, 485999	9,471	0.35
Chemicals and Allied Products, N.E.C.	5169	42269	7,337	0.27
All Other SIC Codes	NA	NA	201,826	7.53
Total			2,681,509	100.00
Notes: 1) Refuse systems (SIC code 4953) were excluded from the analysis because they are likely to be fuel blenders; the intent was to characterize the original sources of hazardous waste. 2) The data on tons was adjusted to account for a data entry error involving the Dow facility in Plaquemine, LA. While the state-reported data used in the 1995 BRS indicate that the facility combusted 2,099,059 tons of waste, the facility actually combusted 22,639 tons. 3) The total tons listed does not equal the total in Figure 3-1 because only the 1995 BRS Generation and Management (GM) forms contained SIC codes, yet the GM forms do not capture data from small quantity generators. (The information in Figure 3-1 was obtained from the 1995 BRS Waste Received (WR) forms, which list the wastes received from small and large quantity generators.) In addition, reporting errors on the part of generators and data entry errors on the part of EPA affect the accuracy of the estimate of tons combusted. NA - Not applicable Source: 1995 BRS data, as reported in RIA for HWC MACT, July 1999				

**Table 3-2. Unit Cost for Use of Incineration (EPA, 1999)
(price per ton in 1996 dollars)**

Liquids		Sludges		Solids	
With Suspended Solids	Highly Contaminated	Less Contaminated	Highly Contaminated	Less Contaminated	Highly Contaminated
\$70	\$301	\$320	\$630	\$683	\$1,281

Table 3-3. Commercial Incinerator Prices, January 2000 * (ETC, 2000)

Type of Waste	Low	Average	High	Unit**
Drummed Halogen Liquid Organics	\$100.00	\$192.00	\$315.00	Per drum
Drummed Non-Halogen Liquid	\$50.00	\$124.00	\$300.00	Per drum
Bulk Non-Halogen Liquid	\$0.25	\$0.59	\$1.60	Per gallon
Lab Packs	\$0.90	\$2.42	\$10.00	Per pound
Drummed Pumpable Sludge	\$100.00	\$207.00	\$400.00	Per drum
Bulk Pumpable Sludge	\$175.00	\$651.00	\$1,500.00	Per ton
Bulk Contaminated Soils	\$375.00	\$559.00	\$1,000.00	Per ton
Aerosols	\$0.30	\$0.47	\$0.75	Per pound

* Survey of Environmental Technology Council (ETC) member companies conducted on sales between July 1, 1999 and December 31, 1999. Low and High prices are the lowest and highest charged by any facility during the survey period. Average is the average of the highest and lowest price reported by each facility, summed and divided by the number of facilities reporting. The prices shown within a particular waste category (e.g., "Bulk Pumpable Sludges") may represent a wide range from low to high for various reasons. For example, wastes from different generators (especially in the case of lab packs) and even from the same generator, can differ based on BTU value, halogen content, compatibility with other waste, and other factors that affect pricing. This survey reflects historical prices for treatment services, and should not be construed as price quotations. Transportation costs are not included.

** Prices may be converted to a common per ton basis using the following approximate conversion factors: (a) 4 drums/ton; (b) 240 gals/ton; or (c) 2,000 pounds/ton

3.2 Applicability to Treating RCRA Appendix VIII Wastes with Chemical Structures Similar to ACWA Chemicals

All seven ACWA technology providers indicated that their technologies can treat organic wastes that have chemical structures similar to the ACWA wastes, but none of these firms provided data on treatment of specific listed RCRA hazardous wastes. Therefore, the RCRA wastes that include constituents with chemical structures similar to ACWA wastes were identified, along with the types of

ACWA wastes that were tested in calendar year 1999 (Demo I). In this evaluation, EPA first identified the type of chemical structure for the ACWA compounds, such as ether, ester, or nitrated aromatic. Then, EPA reviewed the chemicals in RCRA Appendix VIII and waste codes for D, F, K, P, and U listed wastes, and identified those wastes with constituents that have similar chemical structures or structural elements, and likely similar treatability.

The results from this comparison, shown in Table 3-4, indicate which RCRA waste codes contain constituents that fall into each of the ACWA waste categories, and which types of ACWA wastes from those categories were tested. For example, Table 3-4 shows that there are 18 specific RCRA waste codes that contain ethers, and that these waste codes share structural similarity with HD (distilled mustard), one of the ACWA wastes tested. This information could be used in conjunction with the results from the ACWA testing program to help identify specific ACWA technologies that would potentially be applicable to specific RCRA waste codes.

Table 3-4. Comparison of Types of ACWA Wastes and RCRA Wastes

ACWA Waste Category	RCRA Waste Codes	ACWA Wastes Tested
ester	D016, F003, U017, U028, U038, U069, U088, U102, U118, U162, U240	dimethyl phthalate, triacetin
ether	D016, D017, F005, K017, P016, U020, U024, U025, U027, U035, U041, U042, U058, U085, U115, U150, U237, U240	HD (distilled mustard)
nitrated aliphatic	F005, P081, U171	Nitrocellulose, nitroglycerin, RDX, tetrazene
nitrated aromatic	D030, D036, F004, K025, K083, K111, P020, P041, P047, P048, P077, U105, U106, U169, U170, U181, U234	Lead styphnate, 2-nitrodiphenylamine, tetryl, trinitrotoluene
inorganic salt	P119, U144	Antimony trisulfide, barium nitrate, lead thiocyanate, potassium chlorate, potassium nitrate
organophosphate ester	D009, K038, K040, P039, P040, P041, P043, P044, P066, P067, P071, P085, P089, P094, P097, P109, P111, U058, U087	GB (sarin), VX
element/other	D008, D010, P056, U151	carbon, lead azide, sulfur

Table 3-4. Comparison of Types of ACWA Wastes and RCRA Wastes (continued)

ACWA Waste Category	RCRA Waste Codes	ACWA Wastes Tested
<p>Notes:</p> <p>1. ACWA waste testing has not yet been completed for all seven technology service providers, and not all ACWA technologies have been identified as effective for treating all ACWA wastes.</p> <p>2. The ACWA wastes include liquid and solid forms, and, for a given site, the corresponding RCRA waste streams may or may not be present in a similar form.</p> <p>3. The ACWA wastes that were considered in this analysis included the following: Composition A5, Composition B and B4, Tetrytol, black powder, HD, VX, GB, RDX, TNT, tetryl, lead azide, lead styphnate, barium nitrate, potassium nitrate (saltpeter), potassium chlorate, antimony sulfide, corundum (aluminum oxide), lead thiocyanate, carbon, sulfur, tetrazene, nitrocellulose (guncotton), nitroglycerin, triacetin, dimethyl phthalate, lead stearate, and 2-nitrodiphenylamine. Composite materials, such as Composition A5 and the fuze fillings (primer mixtures), were converted into individual chemicals. The additional breakdowns are:</p> <p style="padding-left: 40px;">Composition A5 = RDX Composition B and B4 = RDX + TNT Tetrytol = tetryl + TNT Black powder = potassium nitrate + carbon + sulfur</p> <p>Specific ACWA chemicals were identified by chemical category for each of the ACWA chemicals (the bold item is the category).</p> <p>HD = ether (HD also is a chlorinated hydrocarbon; this analysis did not include address chlorinated hydrocarbons as a separate chemical category) VX, GB = organophosphate ester RDX = 1,3,5-trinitro-1,3,5-triazine = nitrated triazine (some herbicides are non-nitrated triazines) TNT = 2,4,6-trinitrotoluene = nitrated aromatic tetryl = N-methyl-N,2,4,6-tetranitroaniline = nitrated aromatic lead azide = azide salt lead styphnate = lead trinitroresorcinate = nitrated aromatic salt barium nitrate, potassium nitrate (saltpeter), potassium chlorate, antimony sulfide, corundum (aluminum oxide), and lead thiocyanate = inorganic salts carbon, sulfur = elements (combustible) tetrazene = tetrazene = tetrazolyl guanyltetrazene hydrate = sui generis nitrocellulose (guncotton) = nitrated aliphatic nitroglycerin = glyceryl trinitrate = nitrated aliphatic triacetin = triglyceride (fatty ester) dimethyl phthalate = ester lead stearate = soap (fatty acid salt) 2-nitrodiphenylamine = nitrated aromatic</p>		

Methods Used to Manage Similar RCRA Wastes

To provide a general indication of the types of management methods used for the RCRA wastes shown in Table 3-4 as having structural elements similar to ACWA wastes, 16 RCRA wastes were selected from those listed in Table 3-4 for a more detailed evaluation. Figure 3-2 lists the hazardous waste codes used in this evaluation. The 16 wastes were selected as wastes that are believed to be among the

Figure 3-2.
Hazardous Waste Codes Used in
this Analysis

D016	F003	K025	K111
D017	F004	K038	P020
D030	F005	K040	P089
D036	K017	K083	U240

wastes generated in the largest amounts (many "U" and "P" RCRA wastes are generated in relatively lesser amounts and were not included in this evaluation).

This evaluation was based on data in the 1997 Biennial Reporting System (BRS). The BRS is EPA's most comprehensive source of data on the generation and management of RCRA hazardous wastes, and is updated once every two years (1997 is the most recent year for which data are available). This evaluation consisted of wastes streams containing selected hazardous waste codes that were reported as (1) generated and managed on site on the BRS Generation and Management (GM) form, and (2) received from off site for management on the BRS Waste Received (WR) form. A summary of the background of the BRS and the methodology used to analyze data in the BRS is shown in Appendix C.

As shown in Appendix C, waste streams were categorized into management methods using the BRS management system type codes reported. The management categories used were:

- **Incineration** (system type codes M041, M042, M043, M044, and M049);
- **Energy recovery** (system type codes M051, M052, M053, and M059);
- **Stabilization** (system type codes M111, M112, and M119);
- **Aqueous organic treatment** (system type codes M081, M082, M083, M084, M085, M089, M091, M092, M093, M094, and M099);
- **Disposal** (system type codes M131, M132, M133, M134, M135, M136, and M137); and
- **Other** (all other system type codes).

Results from BRS Queries

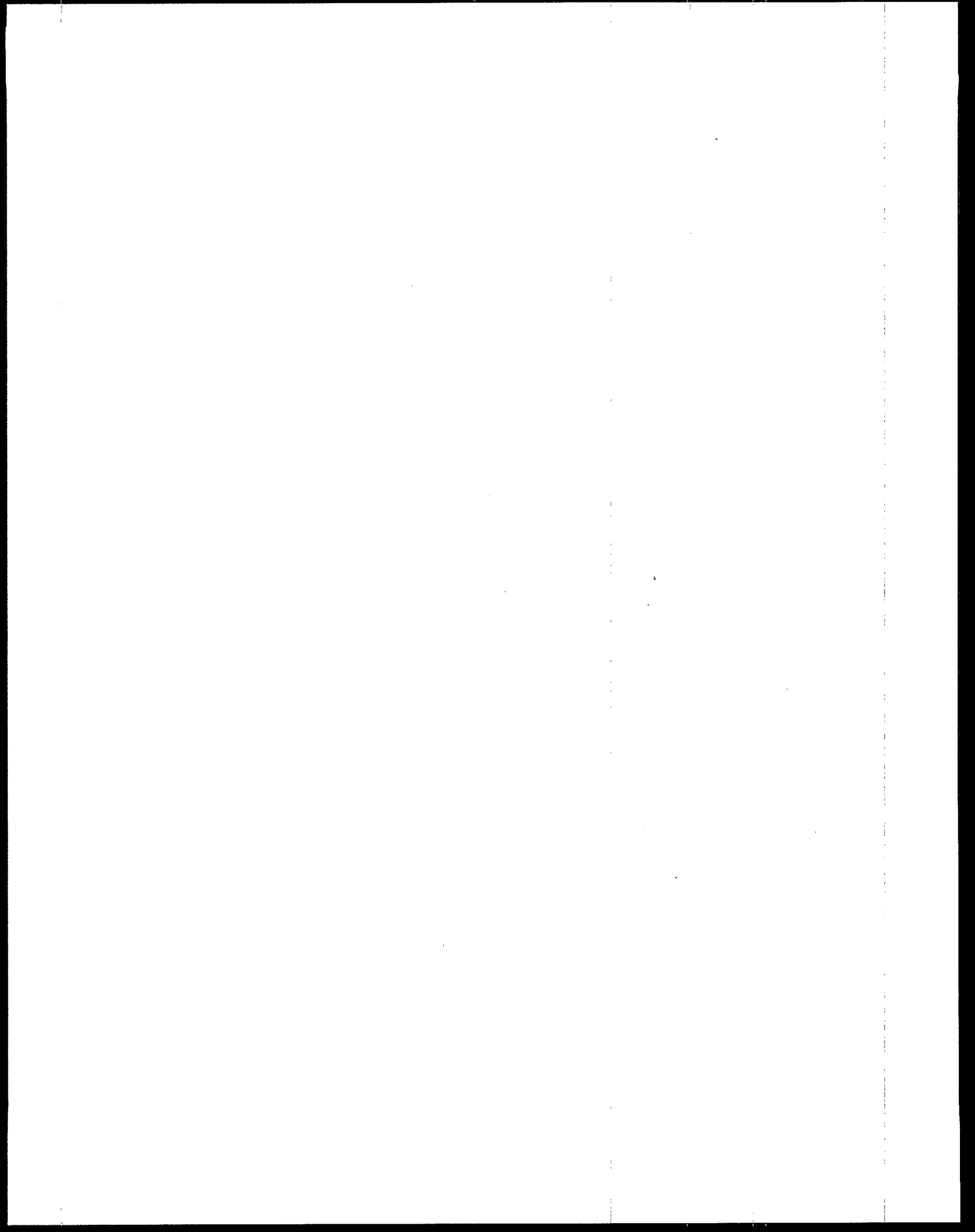
Table 3-5 presents a summary of the management methods identified for the selected RCRA hazardous waste codes generated and managed on site. As shown on Table 3-5, the total quantity of these 16 wastes managed ranges from 39,665 tons/year (for K040) to 115,057,200 tons/year (for F005), with the majority of the wastes managed by aqueous organic treatment or disposal. The three spent solvent wastes (F003, F004, F005) are the wastes (from the list of 16) that have the largest quantity managed.

The BRS contains data that allows a more detailed understanding of these waste quantities, and these more detailed data are presented in Appendix C. Appendices C-1 and C-2 presents a summary of the management methods identified for the selected RCRA hazardous waste codes generated and managed on site for solids and liquids, respectively. Appendices C-3 and C-4 presents the management of liquids generated and managed on site and received from off site for management, respectively. Appendices C-5 and C-6 presents the management of solids generated and managed on site and received from off site for management, respectively. Appendix C-7 provides a summary of the BRS system type codes and their descriptions.

Table 3-5. Management Methods for Selected Wastes Generated and Managed On Site * (EPA, 1997)

EPA Hazardous Waste Code	Incineration (tons)	Energy Recovery (tons)	Stabilization (tons)	Aqueous Organic Treatment (tons)	Disposal (tons)	Other (tons)	Total Managed (tons)
D016	25,959	336	58,548	2,237	87,476	11,781	186,337
D017	9,839	336	32,479	193	79,437	4,282	126,567
D030	59,328	174,345	60,460	810,779	328,392	124,476	1,557,781
D036	66,697	188,255	62,674	495,188	841,840	51,588	1,706,243
F003	717,550	570,032	126,262	44,424,998	23,413,134	1,243,317	70,495,292
F004	239,400	222,418	114,745	42,716,729	42,114,625	117,656	85,525,573
F005	611,813	454,619	134,682	44,690,988	68,169,833	995,266	115,057,200
K017	3,840	61,762	43,103	0	7,068	2,159	117,932
K025	8,496	56,697	39,905	0	6,815	1,524	113,438
K038	200,986	124	35,437	0	477	429	237,453
K040	4,338	366	34,041	160	239	521	39,665
K083	11,655	145,227	47,894	180	7,204	7,152	219,312
K111	7,915	902	31,772	336,032	3,461,814	442,467	4,280,902
P020	7,486	232	46,398	93,498	312	759	148,685
P089	5,710	262	47,561	160	259	705	54,658
U240	25,751	7,653	47,708	160	33,594	1,677	116,542

* Note that it is not appropriate to sum any of the columns on this table (such as for the total amount of waste treated by incineration). Waste streams carrying more than one waste code of interest were accounted for under each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.



4.0 POTENTIAL FOR APPLICATION OF ACWA TECHNOLOGIES TO TREAT CONTAMINATED WASTES AND MEDIA

To evaluate the potential applicability of the seven ACWA technologies to treat contaminated wastes and media, EPA used data supplied by the ACWA technology providers, including performance data and information on the key factors that affect use of the ACWA technologies.

As shown in Table 4-1, the ACWA technologies have previously been tested on or used to treat contaminated wastes and media. Waste matrices treated include process wastes, and contaminated soil, groundwater, sludges, and sediments. Process wastes include items such as waste oils, paints, pure or off-spec products, electrical equipment, concrete, and metals. Prior work has been completed on contaminants such as chlorinated solvents, chlorofluorocarbons (CFCs), dioxins/furans, explosives, PCBs, and pesticides, as well as on chemical weapons (chemical weapons are not described further in this report).

The applications that are considered to have been completed at a full-scale include a commercial SETTM facility in the U.S.; a commercial processing GPCR unit in Kwinana, Western Australia, and a demonstration GPCR unit at St. Catharines, in Ontario, Canada. The unit in Australia processes mainly PCB-contaminated electrical equipment such as ballasts, capacitors, and oils, and has also processed DDT residuals. The unit in Ontario processed PCB-, chlorobenzene-, and dioxin-contaminated soil, electrical, concrete, and other solid wastes.

One of the applications discussed above has been completed at a federal Superfund site. A demonstration-scale test of the SETTM process was used to treat PCB-contaminated sediments at the New Bedford Harbor (Sawyer Street) Superfund site, in Massachusetts.

As discussed earlier in this report, there are technology providers other than those in the ACWA program that offer technologies similar to those in the ACWA program (e.g., chemical oxidation and reduction technologies). Appendix B to this report provides information about these additional service providers.

Key Factors

There are several key factors that are generally considered for use of the ACWA technologies for treatment of contaminated wastes and media, including those concerning material handling and residuals (e.g., air emissions), and cost. Table 4-2 provides a summary of the information provided by the technology service providers relative to material handling and residuals factors.

Table 4-2 shows that the technologies can handle materials in solid, liquid, or gaseous phases. The SILVER IITM and PWCTM processes can handle either solid or liquid phases directly, generally without preprocessing, while the other technologies may require some preprocessing. For example, the SETTM process may require that solids be crushed or shredded prior to treatment, and that wet sludges be dewatered; the GPCR process may require that materials be able to be volatilized or atomized prior to injection, or converted to a liquid phase; and the ICBTM and SCWO processes may require that materials be in a liquid or slurry phase prior to treatment.

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

Table 4-1. Summary of the Prior Work Completed by ACWA Technology Service Providers for Treatment of Contaminated Wastes and Media (as described in Section 2 of this report)

Media/ Contaminant	ACWA Technology Service Provider and Technology						
	AEA's SILVER II™	AlliedSignal's ICB™	Commodore's SET™	Eco Logic's GPCR	Foster Wheeler SCWO	General Atomics' SCWO	Startech's PWC™
Treatment of Contaminated Soil							
Chlorinated solvents			T			B*	T
Explosives			B				P*
PCBs			P	P		B*	T
Pesticides			P				T
Treatment of Contaminated Groundwater							
Chlorinated solvents		P			T	P*	T
PCBs				P	T	P*	T
Treatment of Process Wastes							
Chlorinated solvents	B		P	P	P	P	P*
Explosives	P		P*	P	T	P	P*
PCBs	B		P	F	T	P	T
Pesticides			B	F	T	B	T

KEY: F - Full-scale applications previously completed
P - Pilot/Demonstration-scale applications previously completed; no F applications
B - Bench/Laboratory-scale applications previously completed; no P or F applications
T - Reported as Theoretically applicable; no B, P, or F applications

* The vendor claims to have performed this demonstration, but no supporting data were provided

Table 4-2. Summary of Key Technical Factors for Use of the ACWA Technologies

ACWA Technology Provider	Material Handling Factors	Residuals Factor
AEA's SILVER II™	Materials can be fed by gravity or by pumping, and can be solids (such as wooden pallets) or liquids	Residuals include salts, nitric acid, spent scrubbing solutions, and off gases
AlliedSignal's ICB™	Materials must be in a liquid phase, such as wastewater or groundwater	Residuals consist of biomass sludge and off gases; this process generates relatively less sludge than similar biotreatment processes
Commodore's SET™	Materials must be able to be penetrated by liquid ammonia; some solids, such as metal, concrete, and wood, must be crushed or shredded prior to treatment; materials with high water content (wet sludges) may need to be dewatered prior to treatment	Residuals are metals salts, the dehalogenated parent compound (no toxic intermediates), and off gases; ammonia and other off gases can be reused in the system
Eco Logic's GPCR	Materials must be able to be volatilized or atomized prior to injection into the GPCR; this might include use of a desorber for solid materials	Residuals include treated solids and off gases such as hydrogen chloride and methane
Foster Wheeler SCWO	Materials must be in a liquid or slurry phase, or converted to a liquid or slurry phase, to be fed to the SCWO	Residuals include treated solids, including inorganic salts, and off gases
General Atomics' SCWO	Materials must be in a liquid or slurry phase, or converted to a liquid or slurry phase, to be fed to the SCWO	Residuals include treated solids, including inorganic salts, and off gases
Startech's PWC™	Materials can be fed by gravity or mechanical action and can be solids, liquids, and/or gases; in general, no size reduction or other preprocessing is necessary	The PWC™ produces synthesis fuel-gas, scrap metal, non-leachable silicate glass and spent gas scrubbing solutions

Treatment residuals include solids, liquids, and gaseous materials. All seven ACWA technologies generate off-gases, and the ACWA program provided limited results on the concentrations of dioxins or dibenzofurans in the off-gases from the three treatment technologies included in the 1999 demonstration testing. These values for dioxins and furans measured in the ACWA program were all less than the emission standard for incinerators. All seven technology providers stated that the technologies are designed and operated so that they will not produce dioxins or dibenzofurans in the off-gases, therefore claiming potential as alternatives to incineration.

EPA requested that all ACWA technology providers identify the cost for use of the ACWA technologies for treatment of RCRA wastes and contaminated media, and some provided limited information about cost. However, these costs were limited to select aspects of a given remediation (such as costs for electricity) and are not presented because of concerns about comparability. The capital and operation and maintenance (O&M) costs for remediation of contaminated sites using the ACWA technologies would vary based on site-specific factors such as matrix characteristics and the presence of debris. One of the criteria for accepting technologies into the ACWA program was that their life cycle costs would be approximately comparable to those for incineration. It is likely that additional information will be made available in the future about the costs for use of the ACWA technologies for treatment of RCRA wastes and contaminated media, and after additional testing is completed for the ACWA technologies.

As discussed in Appendix A of this report, in an effort related to the ACWA program, the DoD is looking at these same technologies for use in the nonstockpile chemical weapons program. In that program, the DoD commissioned Mitretek to provide an independent evaluation of the relative costs for using the ACWA technologies in the nonstockpile program. Mitretek performed this evaluation by reviewing proprietary information from the proposals prepared by the ACWA vendors in response to the original solicitation by the Army for the ACWA program, and from the ACWA demonstration study plans. The results from Mitretek's evaluation are provided in their report "Assessment of ACWA Technologies and Equipment for Treatment of Non-Stockpile Wastes and Chemical Material"; MTR 1999-32V1; May 1999.

While the information in the Mitretek report may provide a general indication of the relative costs for use of the technologies for treatment of RCRA wastes and contaminated media, it is important to note that their scope was to make recommendations concerning use of the hardware that had been procured under the ACWA program. Because the U.S. government had already purchased this hardware, the costs reflect only the subsequent operation of those specific units, and may not accurately reflect the costs of similar units designed for processing other waste materials, such as RCRA waste streams or contaminated media. In addition, subsequent to publication of the Mitretek report, the ACWA program began demonstrating the four additional ACWA technologies; according to Mitretek, the government's procurement of these additional technologies rendered invalid several of the costs used in their analysis.

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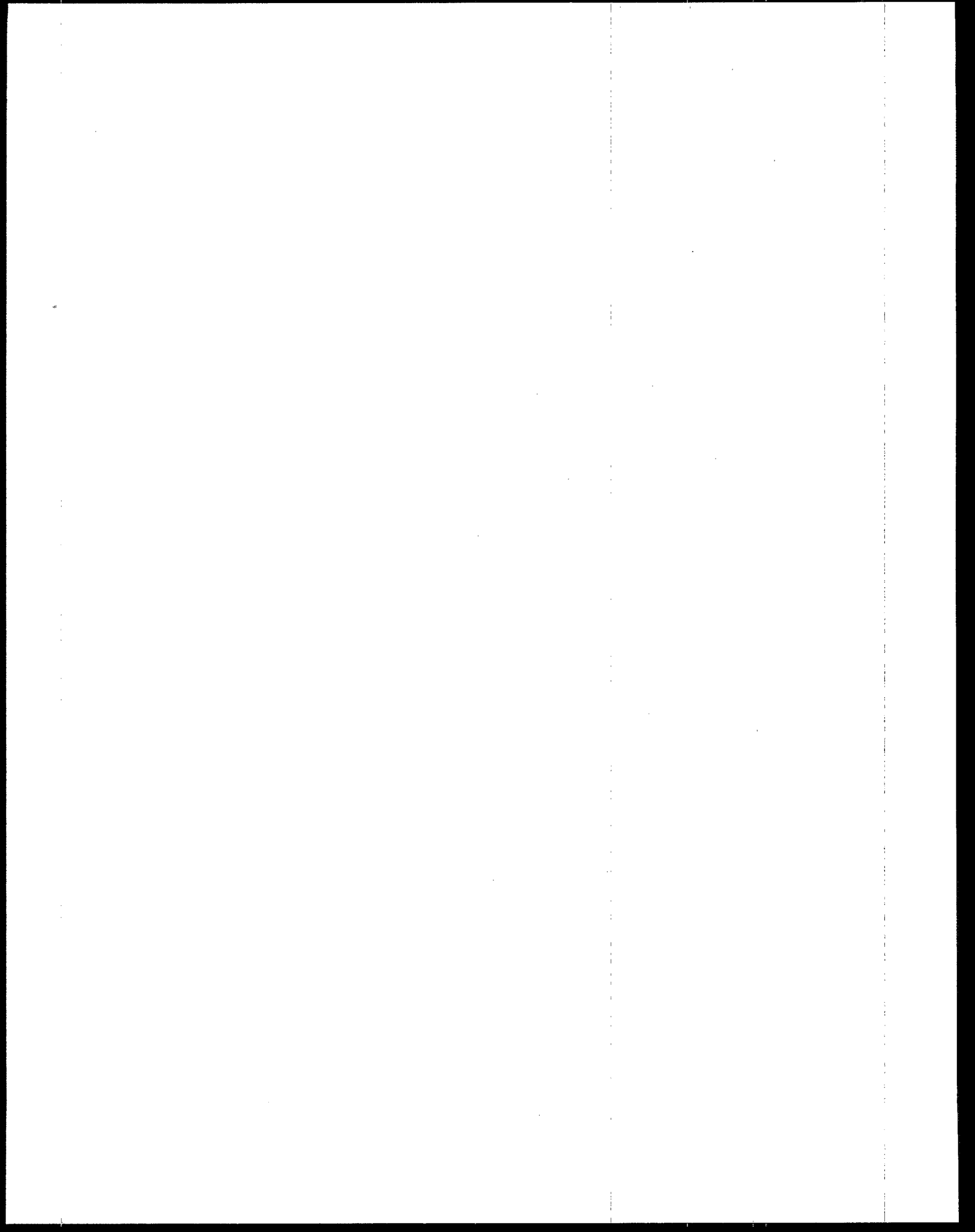
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APPENDIX A

Exhibit A-1. Additional Background on the ACWA Program

Under the ACWA program, the Under Secretary of Defense for Acquisition and Technology submitted Reports to Congress on the ACWA program in December 1997 and December 1998, and a Supplemental Report to Congress in September 1999, on the results of their evaluation of ACWA technologies. A Dialogue on ACWA, comprised of DoD staff from headquarters and the affected sites, EPA staff, stakeholders from the affected communities, state regulators and tribal representatives, representatives of national activist organizations, and other concerned entities, contributed to these efforts. These reports, and other relevant information about the ACWA program, are available on the ACWA web site at <http://www.pmacwa.org>.

DoD selected the ACWA technologies to be tested under the ACWA program based on the following criteria: process efficacy; process performance; effectiveness; waste by-products; sampling and analysis; process maturity; process operability; process monitoring and control; applicability to chemical weapons; safety; design or normal facility occupational impacts; facility accidents with worker impact; facility accidents with public impact; effluent characteristics and impact on human health and the environment; and completeness of effluent characterization.

The Reports to Congress prepared by DoD address the same technology providers and technologies as are covered in this report, and focus primarily on the demonstration testing performed on ACWA wastes. For example, the most recent Report to Congress (September 1999) discusses demonstration testing preparations, operations, and results. It provides an overall evaluation and conclusions about the testing conducted under Demo I, for technologies from Parsons/AlliedSignal, General Atomics, and Burns & Roe. The ACWA technologies were tested in Demo I on chemical weapons agents (i.e., mustard and nerve agent), as well as on energetic materials found in chemical weapons (tetrytol, Comp B, and double base rocket propellant), and on selected secondary wastes, such as wood, fiberglass, Demilitarization Protective Ensemble (DPE) suits, butyl rubber, and charcoal. Testing of the remaining four ACWA technologies is planned for testing in 2000. The Report to Congress does not expand on these technologies' potential applicability to RCRA waste streams or contaminated media.

Other key milestones for the ACWA program include the following.

- May 1, 1998 - Task orders were awarded to six technology service providers (AEA, Teledyne-Commodore, Lockheed Martin, Parsons/AlliedSignal, General Atomics, and Burns & Roe) to develop work plans for demonstrating alternatives
- July 29, 1998 - Three technology service providers were selected for demonstration testing in 1999 (Demo I): Parsons/AlliedSignal, General Atomics, and Burns & Roe
- February 28, 2000 - Technology service providers were selected for demonstration testing in 2000 (Demo II): AEA, Teledyne-Commodore, Eco Logic, and Foster Wheeler
- July - September, 2000 - Demo II testing to be conducted
- March, 2001 - Final Supplemental Report to Congress planned to be completed

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

The National Research Council (NRC) has prepared a report, dated August 1999, on their review and evaluation of alternative technologies for demilitarization of assembled chemical weapons, which is available through their web site at [<http://www.nap.edu/catalog/9660.html>](http://www.nap.edu/catalog/9660.html).

DoD also has other programs that are related to the ACWA program, including the Alternative Technologies (Alt Tech) program, and the nonstockpile program. These programs are also considering the potential for use of the ACWA technologies for their program needs.

Exhibit A-2. Summary of ACWA Technology Providers and Technologies Relevant to EPA Effort

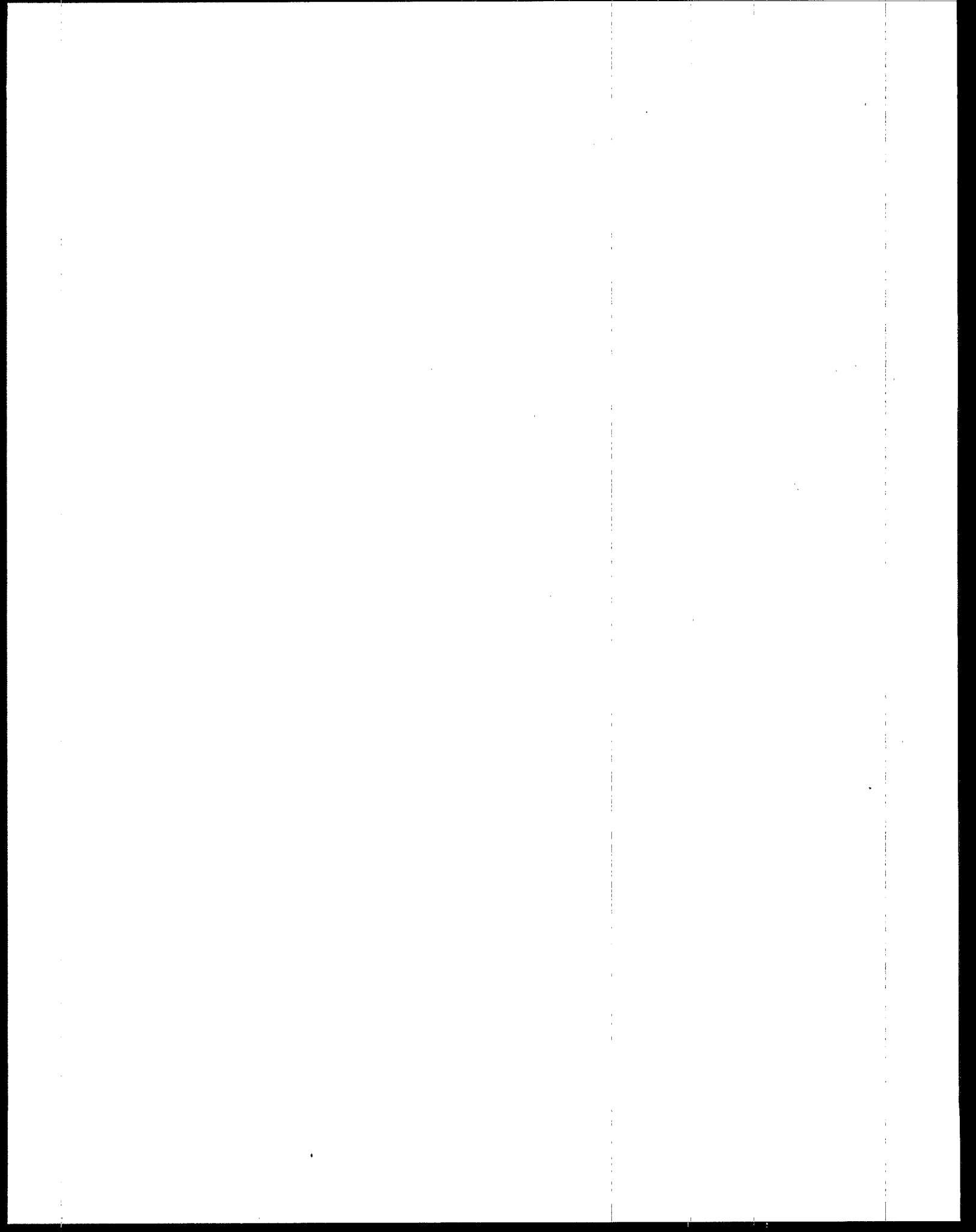
ACWA Technology Provider	Technology Provider or Team Member with Technology Relevant to EPA Effort	Relevant Technologies	Additional Considerations
AEA Technology PLC	AEA	SILVER II™	None
Parsons/AlliedSignal	AlliedSignal (now known as Honeywell)	Immobilized Cell Bioreactor (ICB™)	Parsons is a technology integrator for the ACWA program; AlliedSignal is the team member that was identified as providing technology relevant to the EPA effort
Teledyne-Commodore LLC	Commodore	Solvated Electron Technology (SET™)	Teledyne-Commodore LLC is a combination of Teledyne Brown Engineering (TBE) and Commodore and was formed specifically to market SET to the chemical weapons industry; Commodore provides the SET technology for industrial applications
Lockheed Martin (Lockheed Martin was a service provider under consideration in Demo I; for Demo II, Eco Logic and Foster Wheeler were contracted directly by PMACWA)	Eco Logic Foster Wheeler	Gas Phase Chemical Reduction (GPCR) Supercritical Water Oxidation (SCWO)	Lockheed Martin is a technology integrator for the ACWA program; Eco Logic and Foster Wheeler are the two members of the Lockheed Martin team that were identified as providing technologies relevant to the EPA effort
General Atomics	General Atomics	SCWO	None
Burns and Roe	Startech	Plasma Waste Converter (PWC™)	Burns & Roe is a technology integrator for the ACWA program; Startech is the team member that was identified as providing technology relevant to the EPA effort

Exhibit A-3. Points of Contact at ACWA Technology Providers and Their Team Members

Company	Point of Contact
<p>AEA Technology PLC http://www.aeat.co.uk</p>	<p>Bob Boylston AEA Technology Engineering Services Inc. 241 Curry Hollow Road Pittsburgh, PA 15236-4696 Telephone: (412) 655-1200 Fax: (412) 655-2928 E-mail: boylston@aeatech.com</p>
<p>AlliedSignal Inc. http://www.alliedsignal.com/em/envsys.htm</p>	<p>Brent S. DeFeo AlliedSignal Inc. Environmental Systems and Services P.O. Box 1053 101 Columbia Road Morristown, NJ 07962-1053 Telephone: (973) 455-5507 Fax: (973) 455-5722 E-mail: brent.defeo@alliedsignal.com</p>
<p>Burns and Roe http://www.roe.com</p>	<p>Ralph N. Dechiaro Burns and Roe Enterprises, Inc. 800 Kinderkamack Road Oradell, NJ 07649 Telephone: (201) 986-4056 Fax: (201) 986-4075 E-mail: rdechiaro@roe.com</p>
<p>Commodore Advanced Sciences, Inc. http://www.commodore.com</p>	<p>Mack Jones Commodore Advanced Sciences, Inc. 2340 Menaul Boulevard NE, Suite 400 Albuquerque, NM 87107 Telephone: (505) 872-6803 Fax: (505) 872-6827 E-mail: mjones@commodore.com</p>
<p>ELI Eco Logic Inc. http://www.eco-logic-intl.com</p>	<p>Sherri E. Woodland, B.Sc. Eco Logic 143 Dennis Street Rockwood, ON, Canada N0B 2K0 Telephone: (519) 856-9591 ext. 241 Fax: (519) 856-9235 E-mail: WoodlaS@eco-logic-intl.com</p>
<p>Foster Wheeler http://www.fwc.com</p>	<p>Al Ahluwalia, P.E. Foster Wheeler Development Corporation John Blizard Research Center 12 Peach Tree Hill Road Livingston, NJ 07039 Telephone: (973) 535-2346 Fax: (973) 535-2242 E-mail: al_ahluwalia@fwc.com</p>

**Exhibit A-3. Points of Contact at ACWA Technology Providers and Their Team Members
(continued)**

Company	Point of Contact
General Atomics http://www.gat.com	Dan Jensen, Ph.D. General Atomics 3550 General Atomics Court San Diego, CA 92121-1194 Telephone: (858) 455-4158 Fax: (858) 455-4111 E-mail: dan.jensen@gat.com
Lockheed Martin Energy Technologies, Inc. http://aes.external.lmco.com	Samuel A. Scheer Lockheed Martin Energy Technologies, Inc. 6707 Democracy Boulevard, Suite 410 Bethesda, MD 20817 Telephone: (301) 897-7008 Fax: (301) 897-7019 E-mail: sam.a.scheer@lmco.com
Parsons Infrastructure & Technology Group, Inc. http://www.parsons.com	Martin N. Fabrick Parsons Infrastructure & Technology Group, Inc. 100 West Walnut Street Pasadena, CA 91124 (626) 440-2079 Fax: (626) 440-6195
StarTech Environmental Corporation http://www.startech.net	Joseph F. Longo Startech Environmental Corporation 15 Old Danbury Road Wilton, CT 06897-2525 Telephone: (203) 762-2499 Fax: (203) 761-0839 E-mail: starmail@startech.net
Teledyne Commodore LLC http://www.tbe.com	Jan Roberts Teledyne-Commodore LLC 300 Sparkman Drive Huntsville, AL 35805 Telephone: (256) 726-3377 Fax: (256) 726-3330 E-mail: jan.roberts@tbe.com



APPENDIX B

Vendors in EPA REACH IT Providing Technologies Similar to Those From ACWA Vendors

EPA has an ongoing effort to update and maintain a database of characterization and remediation technologies, known as EPA REACH IT (<<http://www.epareachit.org>>). This database is used by site owners, technology providers, and other environmental professionals to better understand the types of technologies currently available and sites where technologies are being used.

Searches of the EPA REACH IT database were conducted in October 1999 to find vendors that offer technologies similar to the ACWA technologies for the cleanup of common RCRA wastes, such as PCBs, organic pesticides, solvents, and other contaminant groups. Exhibit B-1 lists the vendors along with a contact, the type of technology (trade name), the number of full scale units that are in design, in construction, or completed, their claims about technology performance, as well as the specific mechanisms that the technologies employ (if specified in the database). It is important to note that information is reported in Exhibit B-1 as provided by the technology vendors in EPA REACH IT, and was not modified for this report. Some vendors were not included in the exhibit if they did not supply information about the type of technology they provide. Information in Exhibit B-1 focuses on the following types of chemical or physical mechanisms that are similar to the ACWA technologies:

ACWA Technology	Chemical or Physical Mechanism
SILVER II	Electrochemical cell, oxidation reactions
Immobilized Cell Reactor	Ex situ Bioreactor, fixed film technologies
Solvated Electron Technology	Chemical reduction
Gas Phase Chemical Reduction	Chemical reduction
Supercritical Water Oxidation	Oxidation reaction
Plasma Waste Converter	High temperature destruction

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

The vendors in Exhibit B-1 were derived from the EPA REACH IT database using an advanced search completed on September 30, 1999 with the following search criteria.

- Technology type -
 - Bioremediation (ex situ) - other
 - Chemical treatment - oxidation/reduction
 - Chemical treatment - other
 - Plasma high temperature recovery
 - Vitrification
- AND
- Contaminant group
 - Explosives/propellants
 - Organic pesticides/herbicides
 - PCBs
 - Polynuclear aromatic hydrocarbons (PAHs)
 - Solvents

The search found 45 vendors with 49 technologies and vendor-supplied performance information on 102 sites. These 45 technologies were then reviewed to identify the primary mechanisms used to treat the wastes and assess whether or not the technology had an analogous treatment mechanism to the ACWA technologies. Of the 49 technologies obtained in the search:

- 1 technology was an ACWA technology (EcoLogic)
- 7 technologies were determined to be similar to ACWA technologies
- 13 did not have adequate descriptions to make a determination
- 28 other technologies in the search contained technologies that did not have treatment mechanisms similar to ACWA technologies, such as
 - Fentons reagent - 2
 - Vitrification - 6
 - Extraction technologies - 3
 - Dissolved oxygen - 4
 - Microorganisms - 10
 - Other technologies (phyto-) - 3

EXHIBIT B-1: Vendors Listed in EPA REACH IT as Providing Technologies Similar to ACWA Technologies

Vendor	Contact	Trade Name	No. of Full-scale Units			Technology Performance Claims	Specific Mechanisms Employed	Patent Information
			Design	Constr.	Compl.			
ACWA Technology: AEA's SILVER II Technology								
None								
ACWA Technology: AlliedSignal's Immobilized Cell Bioreactor								
EnSolve Biosystems	Jason Caplan President, CEO (919) 755-9788 Fax: (919) 832-5980 [no email avail.]	EnCell Bioreactor	50	0	2	<ul style="list-style-type: none">Remediates groundwater, lagoon, or processed wastewater contaminated with petroleum hydrocarbons, alcohols, nitroaromatics, solvents, and surfactantsProvides skid-mounted integrated design for site installationsAchieves 99 percent removal for wastewater	Specialized microorganisms Proprietary bacterial support media (fixed film) Passive nutrient and pH adjustment system	Patent pending
Dames and Moore	Joseph Tarsavage, PE Senior Chemical Engineer Phone: (215) 657-5000 X2010 Fax: (215) 657-5454	Bioinfiltration	3	5	5	<ul style="list-style-type: none">Treats hydrocarbons, phenols, chlorinated compounds, and alcoholsProvides greater lateral influence than other bioremediation technologies	Combines in-situ bioremediation of soils with ex-situ bioremediation of groundwater Pumps groundwater through aboveground bio-process train then reinjects it through infiltration gallery in contaminated soil	Patent pending

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

Vendor	Contact	Trade Name	No. of Full-scale Units			Technology Performance Claims	Specific Mechanisms Employed	Patent Information
			Design	Constr.	Compl.			
ACWA Technology: Commodore's Solvated Electron Technology and Eco Logic's Gas Phase Chemical Reduction								
High Voltage Environmental Applications	William J. Coope President Phone: (941) 418-4832	E-Beam	3	1	1	<ul style="list-style-type: none">Organic contaminants are destroyed resulting in the formation of carbon dioxide, water, and halide saltsNon-selective destruction process with demonstrated capability to destroy 140 hazardous organicsNo pre- or post-treatment requiredNo air emissions	Processing of liquid streams containing suspended solids, sediments, or sludge Utilizes insulating core transformer electron accelerators Injects stream of electrons into flowing stream of contamination producing a highly reactive species: reducing aqueous electron, hydrogen atom, and hydroxyl radical	Patented with additional patents pending Registered trademark Vendor has exclusive license

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

Vendor	Contact	Trade Name	No. of Full-scale Units			Technology Performance Claims	Specific Mechanisms Employed	Patent Information
			Design	Constr.	Compl.			
ACWA Technology: Foster Wheeler and General Atomics' Supercritical Water Oxidation								
Delphi Research, Inc.	Terry Rodgers President Phone: (505) 243-3111 Fax: (505) 243-3188	DETOX (SM)	0	1	0	<ul style="list-style-type: none">• Destruction efficiencies greater than 99.99999 percent• Treats all organic compounds and concentrates metals• Products are carbon dioxide, water, inert solids in waste stream, and concentrated residue of toxic metals as oxides or salts	<p>Catalyzed wet oxidation waste stream process for non-thermal oxidation of materials</p> <p>Contaminated stream is introduced to the DETOX solution in a vessel</p> <p>Off-gas is condensed to remove water and hydrogen chloride while other gases may be released or re-circulated</p>	Patent pending
G.E.M., Inc.	Cleve A. Bond President Phone: (501) 337-9410 Fax: (501) 337-1208	Not identified	1	0	0	<ul style="list-style-type: none">• Treats hydrocarbons, PCBs, PCPs, and possibly dioxins• Products are non-hazardous aluminum compounds	<p>Operates as a closed system in which contaminants react with aluminum oxide and either an acid or caustic</p> <p>Treatment occurs in a heated pressure chamber with off-gasses condensed and possibly treated before released</p> <p>Residuals can be adsorbed to rehydratable alumina</p>	#4,919,819

Potential Applicability of ACWA Technologies to RCRA Waste Streams and Contaminated Media

Vendor	Contact	Trade Name	No. of Full-scale Units			Technology Performance Claims	Specific Mechanisms Employed	Patent Information
			Design	Constr.	Compl.			
ACWA Technology: Startech's Plasma Waste Converter								
En-Dyn	Randy Brown President Phone: (701) 775-5325 Fax: (701) 775-9587	Low Temperature Plasma	0	0	0	<ul style="list-style-type: none">• Treats all organic contaminants as well as agrichemicals, oils, and diesel fuel• Reductions range between 93 and 99 percent• Products are water, sterile inorganic material, and gaseous carbon dioxide and water	Plasma is formed when energy is electromagnetically added to a gas resulting in a core temperature of 10,000 degrees Celsius Bulk gas temperature does no exceed 150 degrees Celsius Plasma promotes oxidation reactions	Vendor has exclusive license, patented, and additional patents pending
MSE Technology Applications, Inc.	Jeffery W. Ruffner Vice President, Technology Commercialization Phone: (406) 494-7412 Fax: (494)-7230	Not identified	0	0	0	<ul style="list-style-type: none">• Final product is a non-leachable ceramic slag• Treats halogenated organics, solvents, and heavy metals	Electron torch operates continuously in an oxygen-rich environment Gases generated (e.g. metal fumes, acids, Nox, and particulates) are treated before being released to the environment	Patent pending

APPENDIX C

Results from Queries of EPA's 1997 Biennial Reporting System for Selected RCRA Wastes

Background and Methodology

Facilities that generate and manage RCRA hazardous waste on site, or generate RCRA hazardous waste and ship it off site for management, report to EPA's BRS using the GM form. Facilities receiving RCRA hazardous waste from off site for management report using the WR form.

It is possible for a single waste stream that is shipped off site for management to be reported twice to the BRS – once by the facility that generated the waste and once by the facility managing the waste. For purposes of this analysis, waste stream information from the management perspective was used. That is, waste streams reported as (1) generated and managed on site on the GM form or (2) received from off site for management on the WR form.

In addition to the quantity of waste generated and/or managed, facilities must provide a description of the waste stream. While generators must provide information on the origin of the waste stream, both generators and managers must provide (1) RCRA hazardous wastes codes that characterize the waste, (2) the waste form (*i.e.*, solid, liquid, sludge, gas), and (3) how the waste was managed (*i.e.*, system type codes). A discussion of how these three descriptions were used in the evaluation is provided below.

Any waste stream containing the waste code shown in Figure 3-2 was included in the evaluation, regardless of the number of other waste codes associated with the stream. Waste streams carrying more than one waste code of interest were accounted for each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.

Waste streams quantities were further classified as liquid or solid/sludge using the BRS form code reported on the GM or WR form. Waste streams with form codes beginning with B1 or B2 (*i.e.*, inorganic liquids or organic liquids, respectively) were classified as liquid. Waste streams with waste form codes beginning with B3 and B4 (*i.e.*, inorganic and organic solids, respectively) and B5 and B6 (*i.e.*, inorganic and organic sludges, respectively) were classified as solid/sludge. Gases (*i.e.*, waste form codes beginning with B7 or B8) were also included as solid/sludges. All other waste streams (*i.e.*, invalid codes) were excluded from the analysis.

Table C-1. Management Methods for Selected Liquid Wastes Generated and Managed On Site and Received from Off Site for Management *

EPA Hazardous Waste Code	Incineration (tons)	Energy Recovery (tons)	Stabilization (tons)	Aqueous Organic Treatment (tons)	Disposal (tons)	Other (tons)	Total Managed (tons)
D016	16,170	158		2,236	7,632	6,104	32,300
D017	4,543	158	0	193		3,842	8,736
D030	42,903	148,207	210	810,778	315,051	118,119	1,435,267
D036	49,291	161,687	210	495,180	840,380	44,097	1,590,845
F003	499,804	496,330	726	44,417,221	23,208,637	1,148,795	69,771,513
F004	52,925	195,403	197	42,716,728	42,003,541	100,930	85,069,724
F005	383,410	380,932	1,033	44,683,282	68,001,282	909,387	114,359,326
K017	84	61,732	22		6,593	877	69,308
K025	4,090	56,667			6,593	283	67,634
K038	197,252	124	22				197,397
K040	464	158	22	160		0	804
K083	4,662	108,330	22	180	6,593	5,139	124,926
K111	2,029	902	22	336,032	3,461,337	439,518	4,239,839
P020	2,605	54		93,498		21	96,178
P089	2,477	54		160	9	18	2,718
U240	11,770	6,645		160	32,652	60	51,287

* Note that it is not appropriate to sum any of the columns on this table (such as for the total amount of waste treated by incineration). Waste streams carrying more than one waste code of interest were accounted for under each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.

**Table C-2. Management Methods for Selected Solid and Sludge Wastes
Generated and Managed On Site and Received from Off Site for Management ***

EPA Hazardous Waste Code	Incineration (tons)	Energy Recovery (tons)	Stabilization (tons)	Aqueous Organic Treatment (tons)	Disposal (tons)	Other (tons)	Total Managed (tons)
D016	9,789	178	58,548	0	79,843	5,677	154,037
D017	5,297	178	32,478		79,437	441	117,831
D030	16,426	26,138	60,250	1	13,341	6,357	122,513
D036	17,406	26,568	62,465	8	1,460	7,491	115,398
F003	217,745	73,702	125,536	7,777	204,497	94,522	723,779
F004	186,476	27,015	114,548	1	111,084	16,725	455,849
F005	228,402	73,687	133,650	7,705	168,551	85,879	697,874
K017	3,756	30	43,081		475	1,282	48,624
K025	4,406	30	39,905		222	1,241	45,804
K038	3,735		35,415		477	429	40,056
K040	3,874	208	34,018		239	521	38,861
K083	6,993	36,898	47,872		611	2,013	94,386
K111	5,887		31,750		477	2,949	41,063
P020	4,881	178	46,398		312	738	52,507
P089	3,233	208	47,561		250	687	51,940
U240	13,981	1,008	47,708		942	1,616	65,255

* Note that it is not appropriate to sum any of the columns on this table (such as for the total amount of waste treated by incineration). Waste streams carrying more than one waste code of interest were accounted for under each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.

Table C-3. Management Methods for Selected Liquid Wastes Generated and Managed On Site *

EPA Hazardous Waste Code	Incineration (tons)	Energy Recovery (tons)	Stabilization (tons)	Aqueous Organic Treatment (tons)	Disposal (tons)	Other (tons)	Total Managed (tons)
D016	2,087	70			6,327	3,816	12,300
D017	2,085	70				3,813	5,968
D030	20,107	107		807,002	313,000	85,735	1,225,951
D036	21,105	3,224		492,353	804,461	3,362	1,324,505
F003	416,449	44,826	1	44,376,958	23,171,480	370,381	68,380,094
F004	15,840	70	8	42,712,995	41,967,473	21,644	84,718,028
F005	311,424	13,257	9	44,659,146	67,961,146	428,142	113,373,125
K017	41	70			6,327	241	6,679
K025	41	70			6,327	241	6,679
K038	197,063	70					197,132
K040	275	70					345
K083	427	70			6,327	241	7,065
K111	2,014	70		335,996	3,461,071	439,476	4,238,627
P020	2,272			93,339		0	95,611
P089	2,260				9		2,269
U240	2,272	70			32,386		34,728

* Note that it is not appropriate to sum any of the columns on this table (such as for the total amount of waste treated by incineration). Waste streams carrying more than one waste code of interest were accounted for under each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.

Table C-4. Management Methods for Selected Liquid Wastes Received from Off Site for Management *

EPA Hazardous Waste Code	Incineration (tons)	Energy Recovery (tons)	Stabilization (tons)	Aqueous Organic Treatment (tons)	Disposal (tons)	Other (tons)	Total Managed (tons)
D016	14,083	88		2,236	1,305	2,287	20,000
D017	2,457	88	0	193		28	2,768
D030	22,795	148,100	210	3,776	2,051	32,384	209,317
D036	28,186	158,463	210	2,828	35,918	40,736	266,340
F003	83,355	451,504	725	40,263	37,157	778,414	1,391,419
F004	37,085	195,333	189	3,733	36,068	79,287	351,696
F005	71,986	367,675	1,024	24,136	40,136	481,245	986,201
K017	43	61,662	22		266	636	62,629
K025	4,050	56,597			266	42	60,955
K038	189	54	22				265
K040	189	88	22	160		0	459
K083	4,235	108,260	22	180	266	4,898	117,861
K111	14	833	22	35	266	42	1,212
P020	332	54		160		21	567
P089	217	54		160		18	448
U240	9,498	6,575		160	266	60	16,559

* Note that it is not appropriate to sum any of the columns on this table (such as for the total amount of waste treated by incineration). Waste streams carrying more than one waste code of interest were accounted for under each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.

Table C-5. Management Methods for Selected Solid and Sludge Wastes Generated and Managed On Site *

EPA Hazardous Waste Code	Incineration (tons)	Energy Recovery (tons)	Stabilization (tons)	Aqueous Organic Treatment (tons)	Disposal (tons)	Other (tons)	Total Managed (tons)
D016	1,689		9		79,227	30	80,955
D017	1,648		9		79,227	27	80,912
D030	2,188	17,608	1		10,029	1,543	31,370
D036	2,133	17,608	1		534	468	20,744
F003	174,694	48,224	34,854	7,660	172,528	7,763	445,723
F004	172,467	5,136	33,929		97,887	1,082	310,501
F005	185,720	48,224	34,854	7,636	147,355	7,726	431,514
K017	2,446	30	69		226	45	2,815
K025	2,318	30			3		2,351
K038	2,236				3		2,239
K040	2,362	30			3		2,395
K083	3,633	23,530			347	1	27,512
K111	2,229				7		2,235
P020	2,935				3	2	2,940
P089	2,400	30			3	2	2,435
U240	2,513	30			3		2,546

* Note that it is not appropriate to sum any of the columns on this table (such as for the total amount of waste treated by incineration). Waste streams carrying more than one waste code of interest were accounted for under each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.

Table C-6. Management Methods for Selected Solid and Sludge Wastes Received from Off Site for Management *

EPA Hazardous Waste Code	Incineration (tons)	Energy Recovery (tons)	Stabilization (tons)	Aqueous Organic Treatment (tons)	Disposal (tons)	Other (tons)	Total Managed (tons)
D016	8,100	178	58,539	0	617	5,647	73,082
D017	3,649	178	32,469		210	413	36,919
D030	14,238	8,530	60,249	1	3,312	4,814	91,144
D036	15,273	8,960	62,464	8	927	7,023	94,654
F003	43,051	25,478	90,683	117	31,968	86,759	278,056
F004	14,009	21,879	80,620	1	13,197	15,643	145,349
F005	42,682	25,463	98,796	69	21,196	78,153	266,359
K017	1,310		43,013		249	1,237	45,808
K025	2,088		39,905		219	1,241	43,454
K038	1,499		35,415		474	429	37,817
K040	1,512	178	34,018		236	521	36,466
K083	3,359	13,367	47,872		263	2,012	66,874
K111	3,658		31,750		471	2,949	38,827
P020	1,946	178	46,398		309	736	49,567
F089	833	178	47,561		247	685	49,505
U240	11,468	978	47,708		939	1,616	62,709

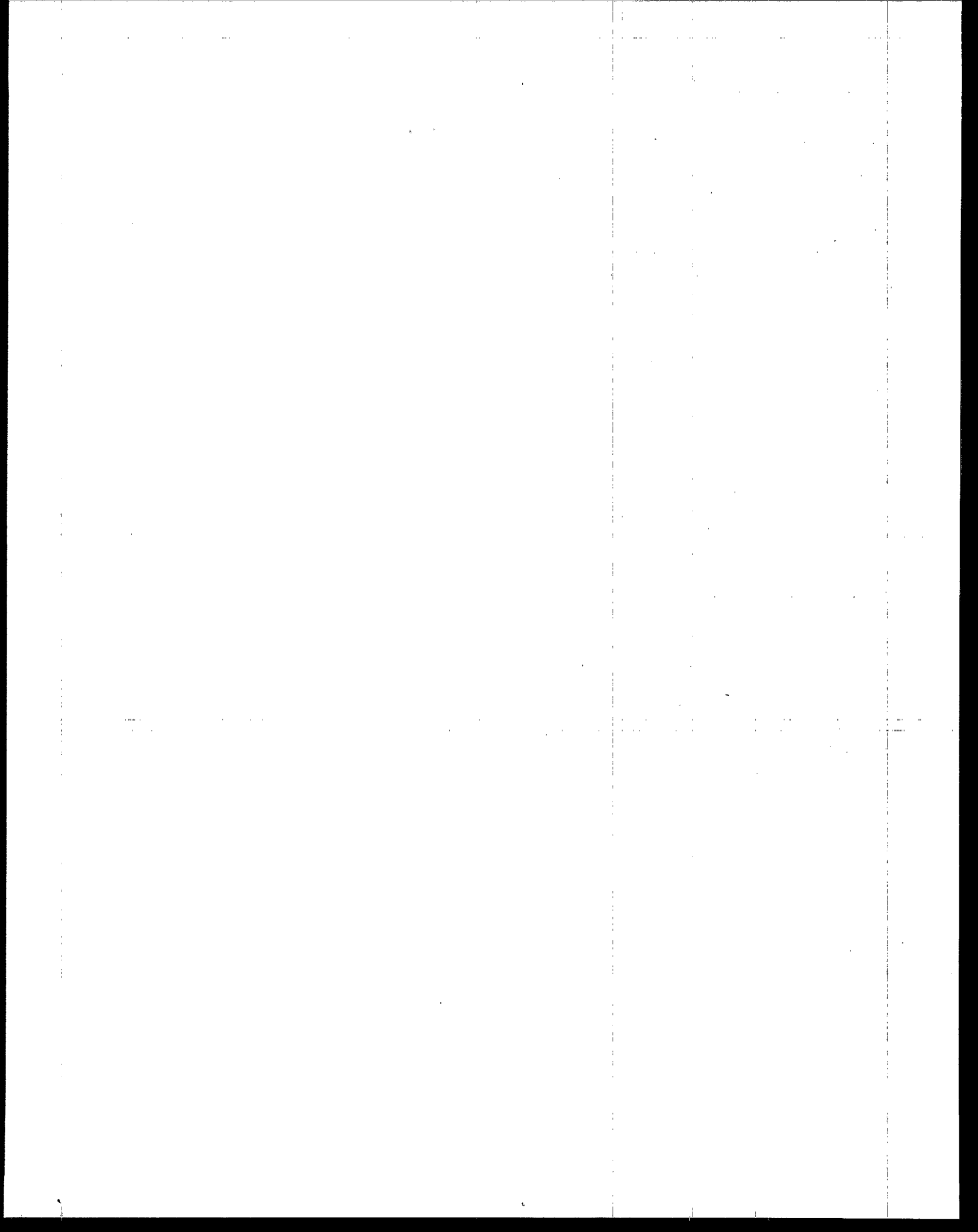
* Note that it is not appropriate to sum any of the columns on this table (such as for the total amount of waste treated by incineration). Waste streams carrying more than one waste code of interest were accounted for under each waste code; therefore, waste quantities could be counted more than once. For example, if 10 tons of a waste contains both 2,4-Dinitrotoluene (D030) and Nitrobenzene (D036), those same 10 tons are reported under both D030 and D036.

Table C-7. RCRA BRS System Type Codes and Descriptions

System Type Codes	Description
M011	High temperature metals recovery
M012	Retorting
M013	Secondary smelting
M014	Other metals recovery for reuse: e.g., ion exchange, reverse osmosis, acid leaching
M019	Metals recovery - type unknown
M021	Fractionation/distillation
M022	Thin film evaporation
M023	Solvent extraction
M024	Other solvent recovery
M029	Solvents recovery - type unknown
M031	Acid regeneration
M032	Other recovery: e.g., waste oil recovery, nonsolvent organics recovery
M039	Other recovery - type unknown
M041	Incineration - liquids
M042	Incineration - sludges
M043	Incineration - solids
M044	Incineration - gases
M049	Incineration - type unknown
M051	Energy recovery - liquids
M052	Energy recovery - sludges
M053	Energy recovery - solids
M059	Energy recovery - type unknown
M061	Fuel blending
M071	Chrome reduction followed by chemical precipitation
M072	Cyanide destruction followed by chemical precipitation
M073	Cyanide destruction only
M074	Chemical oxidation followed by chemical precipitation
M075	Chemical oxidation only
M076	Wet air oxidation
M077	Chemical precipitation
M078	Other aqueous inorganic treatment: e.g., ion exchange, reverse osmosis
M079	Aqueous inorganic treatment - type unknown
M081	Biological treatment
M082	Carbon adsorption
M083	Air/steam stripping
M084	Wet air oxidation
M085	Other aqueous organic treatment
M089	Aqueous organic treatment - type unknown

Table C-7. System Type Codes and Descriptions (continued)

System Type Codes	Description
M091	Chemical precipitation in combination with biological treatment
M092	Chemical precipitation in combination with carbon adsorption
M093	Wet air oxidation
M094	Other organic/inorganic treatment
M099	Aqueous organic and inorganic treatment - type unknown
M101	Sludge dewatering
M102	Addition of excess lime
M103	Absorption/adsorption
M104	Solvent extraction
M109	Sludge treatment - type unknown
M111	Stabilization/chemical fixation using cementitious and/or pozzolanic materials
M112	Other stabilization
M119	Stabilization - type unknown
M121	Neutralization only
M122	Evaporation only
M123	Settling/clarification only
M124	Phase separation (e.g., emulsion breaking, filtration) only
M125	Other treatment
M129	Other treatment - type unknown
M131	Land treatment/application/farming
M132	Landfill
M133	Surface impoundment (to be closed as a landfill)
M134	Deep well/underground injection
M135	Direct discharge to sewer/POTW (no prior treatment)
M136	Direct discharge to surface water under NPDES (no prior treatment)
M137	Other disposal
M141	Transfer facility storage -- waste was shipped off site without any on-site treatment, disposal, or recycling activity





United States
Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office (5102G)
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